Underwater Image Enhancement via Minimal Color Loss and Locally Adaptive Contrast Enhancement

Weidong Zhang, Peixian Zhuang, Haihan Sun, Guohou Li, Sam Kwong, Chongyi Li

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Group 6

B09902068 凌暄、R10922A23 郭毅遠、R10922194 蔡昀儒

Outline

- Introduction
- Problem Definition
- **Algorithm & Implementation**
- **Results Comparison**
- References

Introduction

Importance of underwater imaging

- Marine scientific expeditions
- Underwater robotics
- Underwater infrastructure inspection
- Recognition of underwater objects

Degraded color and contrast of underwater image

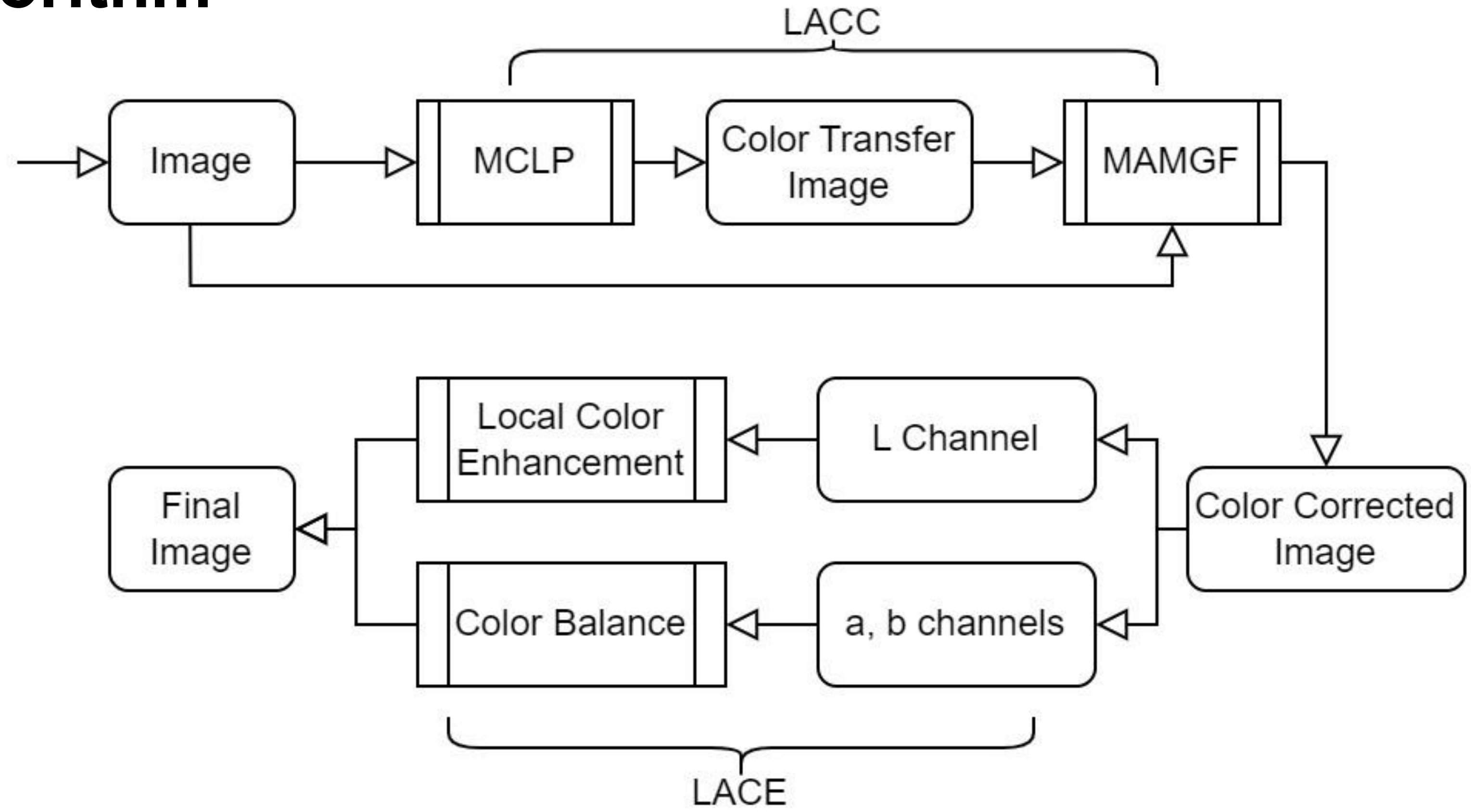
- Wavelength-dependent light absorption and scattering
- Insufficient lighting
- Low-end underwater imaging devices

Problem Definition

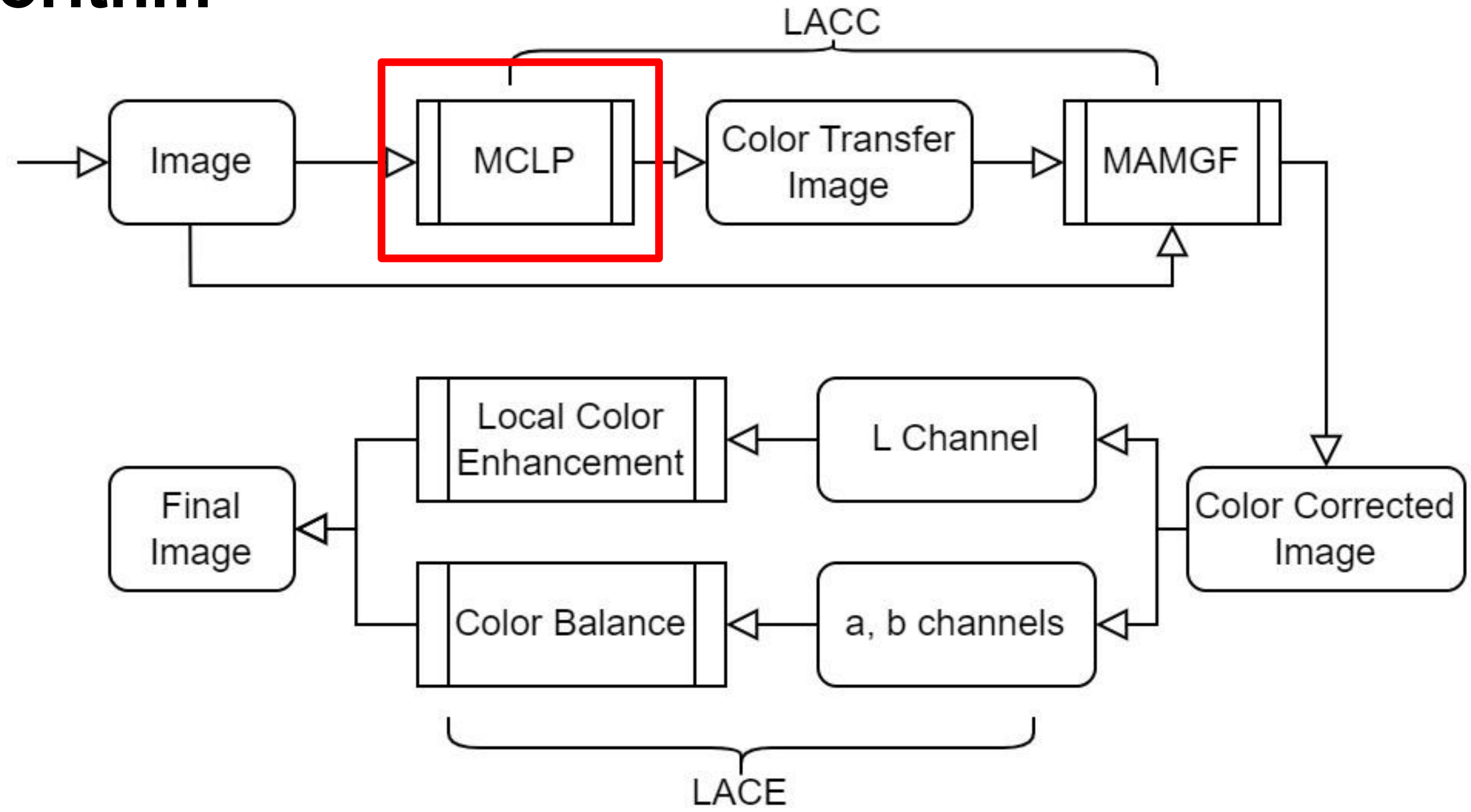
Develop a underwater image enhancement method that is:

- Generalizable
- Efficient to implement
- Avoid over-enhance
- Avoid over-saturate
- Avoid color-deviate

Algorithm


LACC
Image
MCLP
Color Transfer Image
MAMGF
Local Color Enhancement
L Channel
Final Image
Color Corrected Image
Color Balance
a, b channels
LACE

Algorithm



LACC
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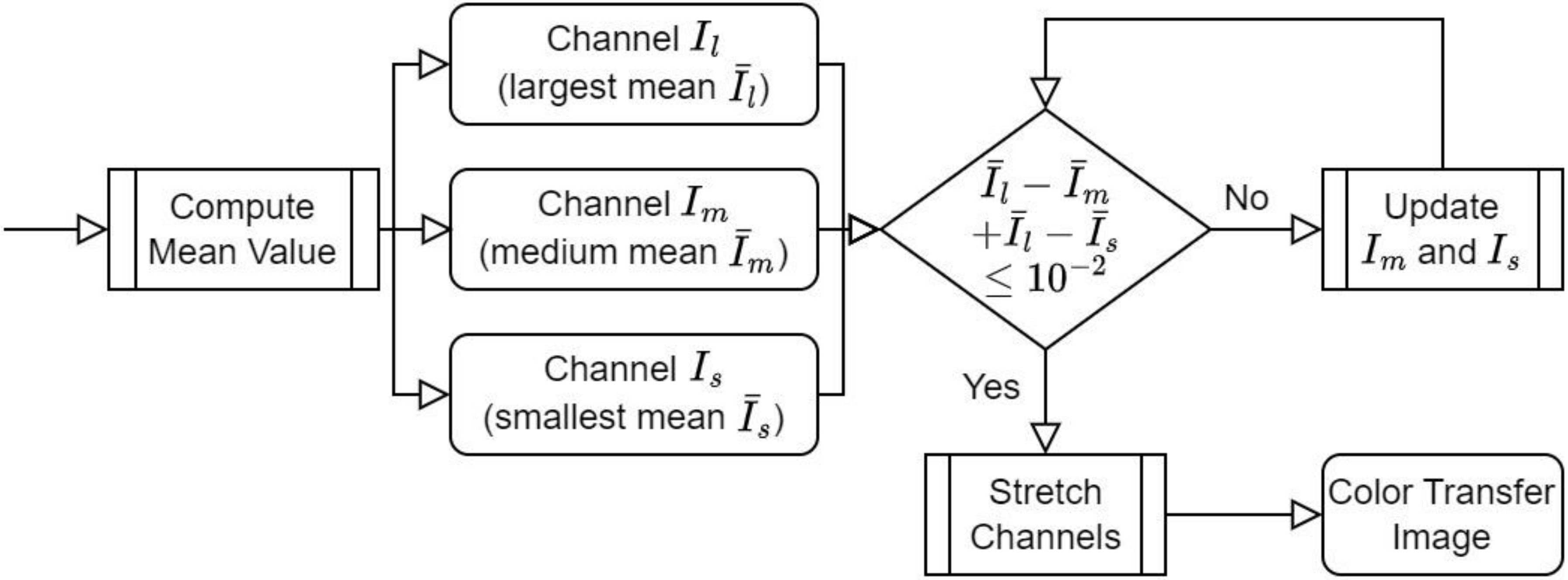
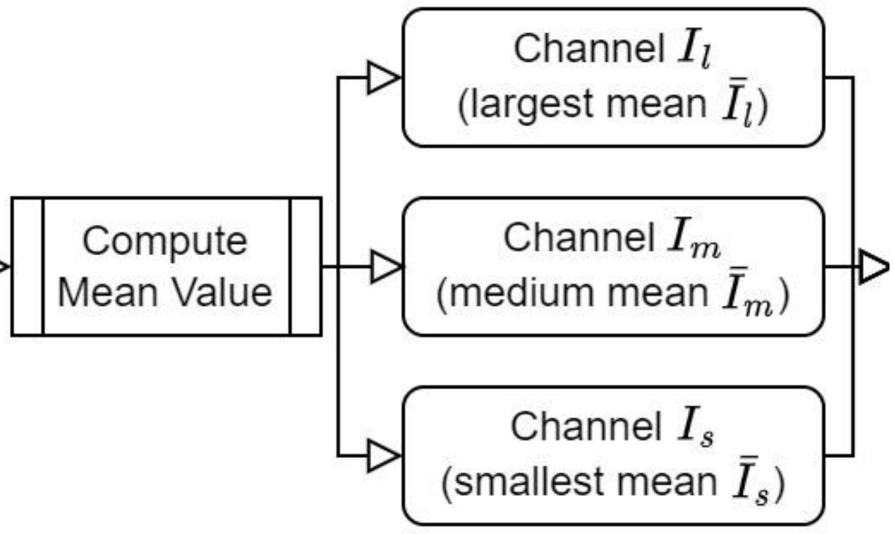
LACC-MCLP



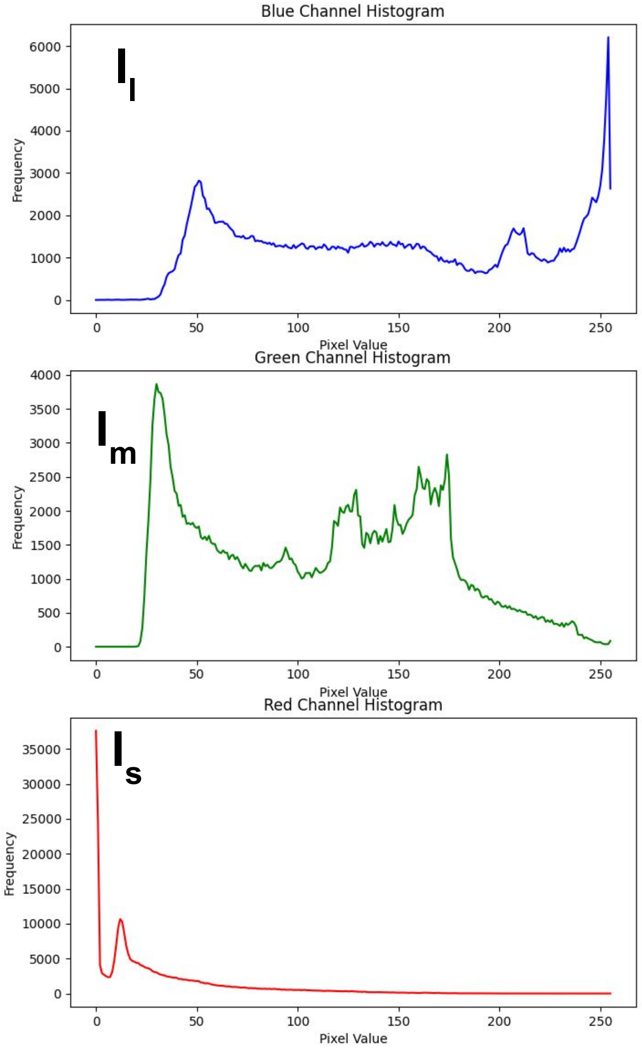
Compute Mean Value
Channel I_l (largest mean $\bar{I}_l$)
Channel I_m (medium mean $\bar{I}_m$)
Channel I_s (smallest mean $\bar{I}_s$)
$\bar{I}_l - \bar{I}_m + \bar{I}_l - \bar{I}_s \leq 10^{-2}$
No
Update I_m and I_s
Yes
Stretch Channels
Color Transfer Image

LACC-MCLP Implementation

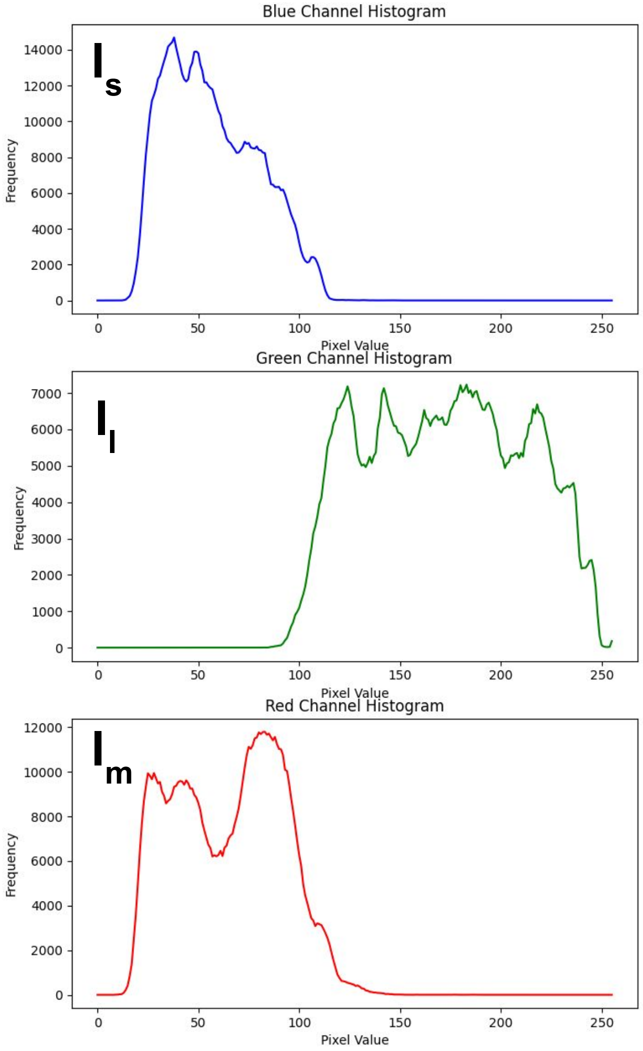


Input: original image

- split to RGB channel
- Calculate the **mean value** of each channel
- **Sort** accordingly into $\mathbf{I_l}$, $\mathbf{I_m}$, and $\mathbf{I_s}$


Blue Channel Histogram
I_l
Frequency
Pixel Value
Green Channel Histogram
I_m
Frequency
Pixel Value
Red Channel Histogram
I_s
Frequency
Pixel Value

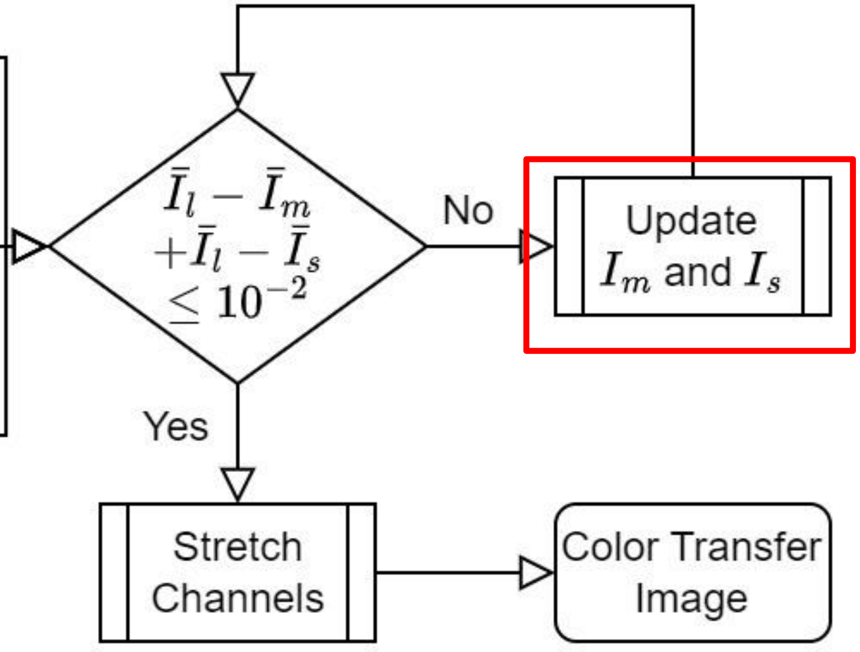
$I_l = B,\ I_m = G,\ I_s = R$



Blue Channel Histogram
I_s
Frequency
Pixel Value
Green Channel Histogram
I_l
Frequency
Pixel Value
Red Channel Histogram
I_m
Frequency
Pixel Value

I_l =G, I_m=R, I_s=B

LACC-MCLP Implementation



The 2 different approaches in the paper:

Version in the text:

$$I_m^{CR} = I_m + (\bar{I}_l - \bar{I}_m) \times I_l$$

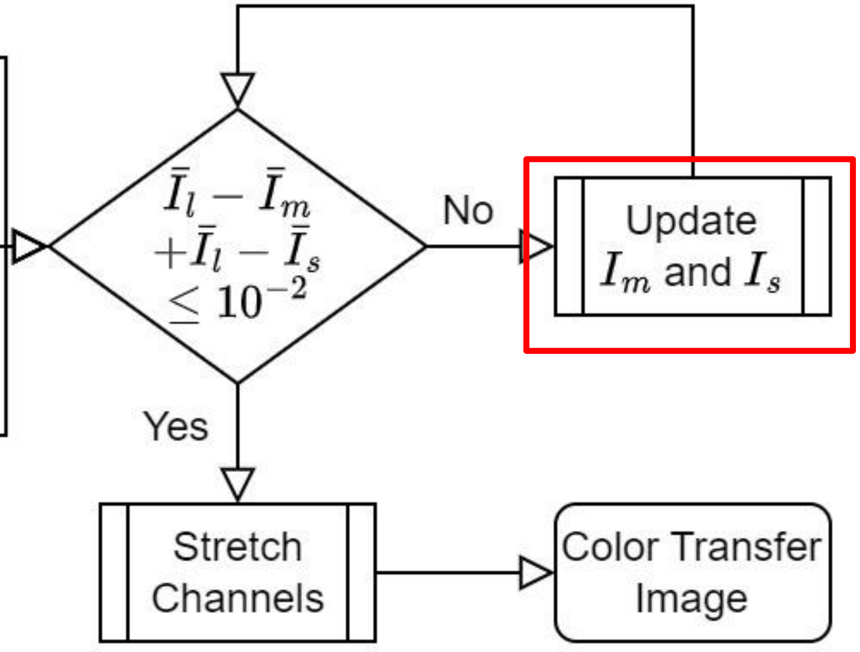
$$\boxed{I_s^{CR} = I_s + (\bar{I}_l - \bar{I}_s) \times I_l}$$

Version in the fig.2:

$$I_m^{CR} = I_m + (\bar{I}_l - \bar{I}_m) \times I_l$$

$$\boxed{I_s^{CR} = I_s + (\bar{I}_m - \bar{I}_s) \times I_m}$$

LACC-MCLP Implementation



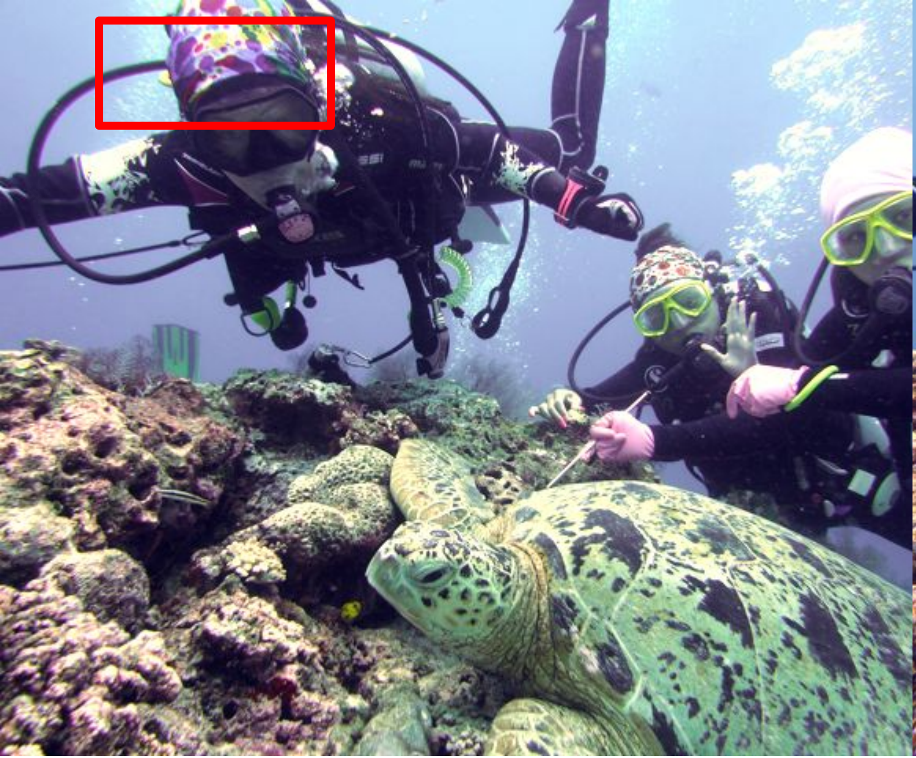
Our approach

$$I_m^{CR} = I_m + \frac{(\bar{I}_l - \bar{I}_m) \times I_l}{\boxed{255}}$$

$$I_s^{CR} = I_s + \frac{\boxed{(\bar{I}_l - \bar{I}_s) \times I_l} + \boxed{(\bar{I}_m - \bar{I}_s) \times I_m}}{2 \times \boxed{255}}$$

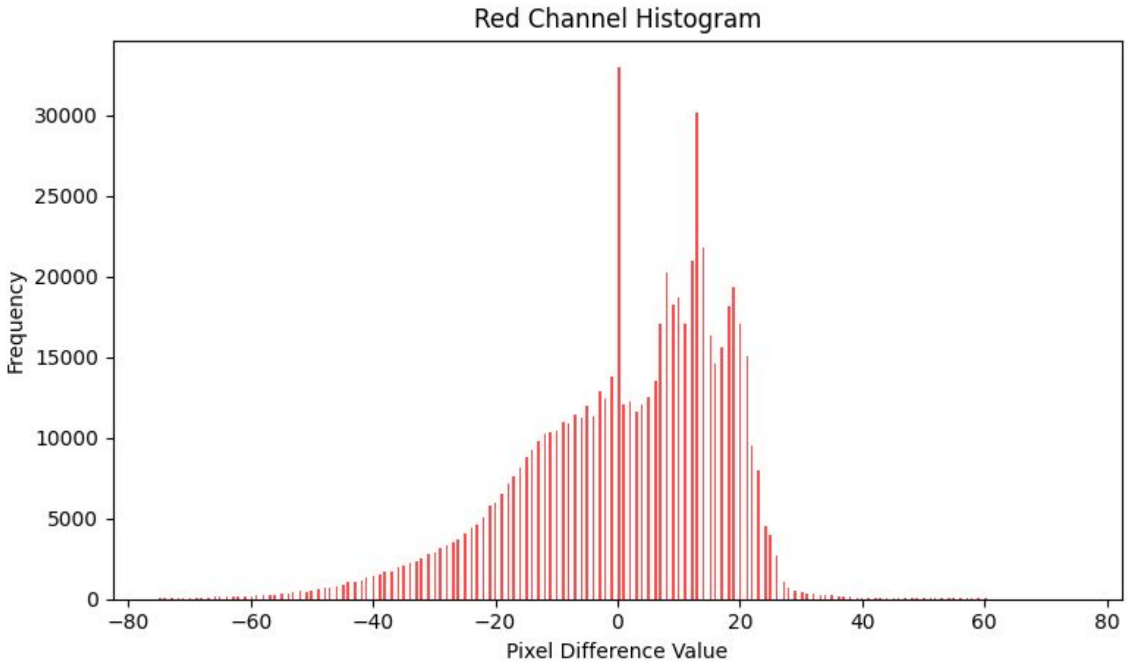
Rationales of modification

1. **The loss function does not converge**
2. **None of the 2 different versions is always superior**



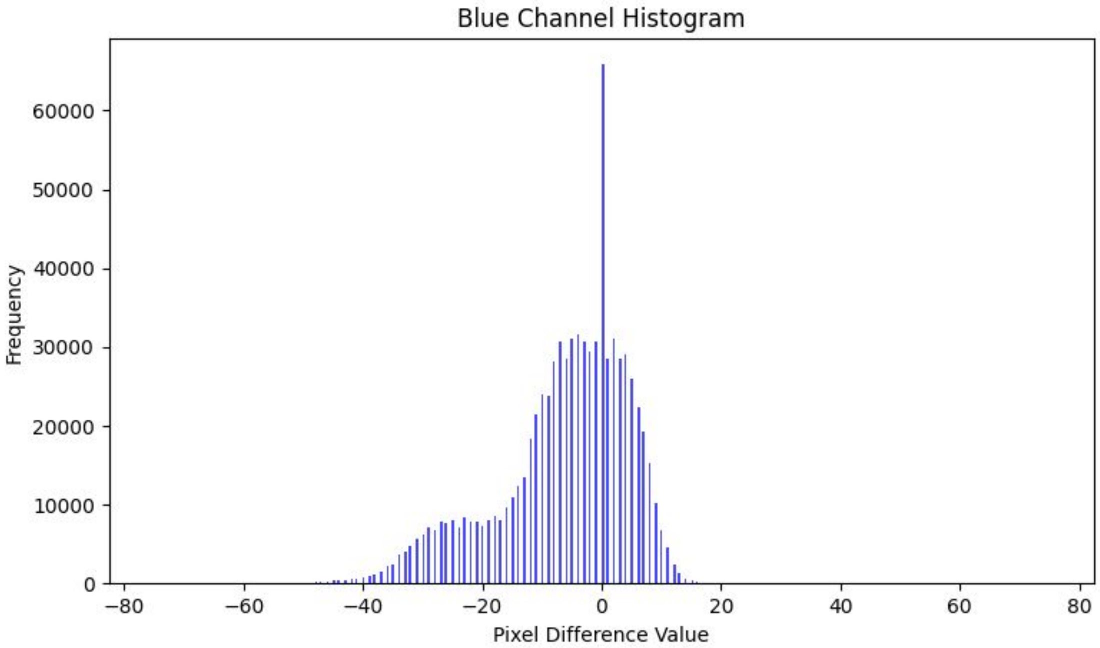
$$I_s^{CR} = I_s + \frac{(\bar{I}_l - \bar{I}_s) \times I_l}{255}$$

$$I_s^{CR} = I_s + \frac{(\bar{I_m} - \bar{I}_s) \times I_m}{255}$$


Red Channel Histogram
Frequency
30000
25000
20000
15000
10000
5000
0
−80
−60
−40
−20
0
20
40
60
80
Pixel Difference Value

$$I_s^{CR} = I_s + \frac{(\bar{I}_l - \bar{I}_s) \times I_l}{255}$$

$$I_s^{CR} = I_s + \frac{(\bar{I}_m - \bar{I}_s) \times I_m}{255}$$



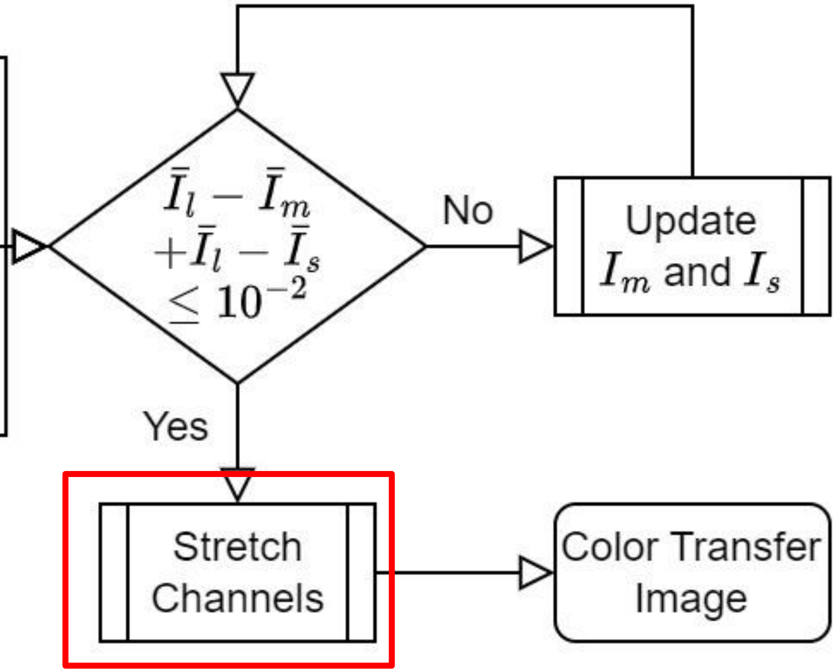
Blue Channel Histogram
Frequency
60000
50000
40000
30000
20000
10000
0
−80
−60
−40
−20
0
20
40
60
80
Pixel Difference Value

Satisfactory results in both cases !!

Our approach

$$I_s^{CR} = I_s + \frac{(\bar{I}_l - \bar{I}_s) \times I_l + (\bar{I}_m - \bar{I}_s) \times I_m}{2 \times 255}$$

LACC-MCLP Implementation



Original approach described in paper

$$I_c^{CR} = 255 \frac{I_c - I_c^{min}}{I_c^{max} - I_c^{min}}, c \in \{R, G, B\}$$

Our approach

1. Stretch **I_l** directly
2. **Clip I_m and I_s to [0,255]** before stretching

Rationales of modification

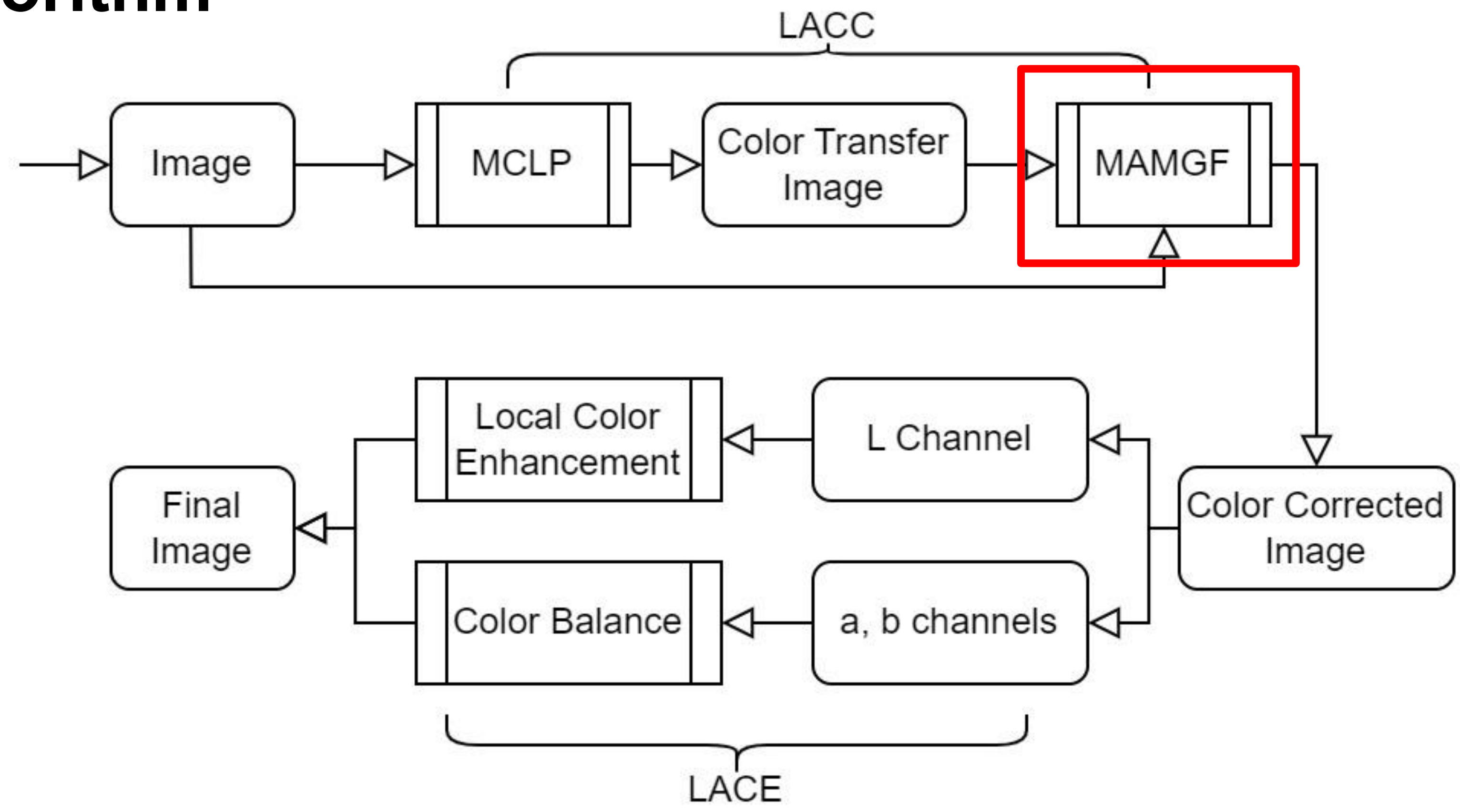
The color correction effect will be reduced without clipping before stretching

Clip I_m and I_s to [0,255] before stretching

No Clipping I_m and I_s before stretching

color correction effect significantly reduced

Algorithm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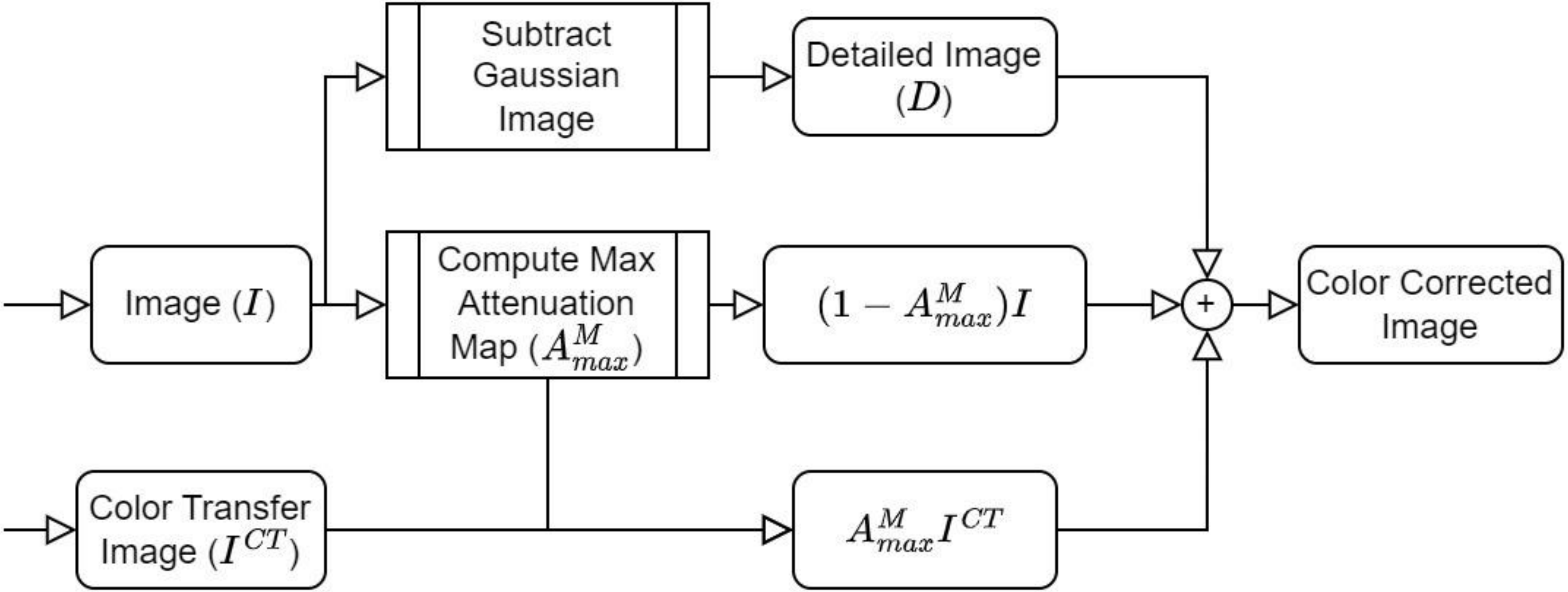
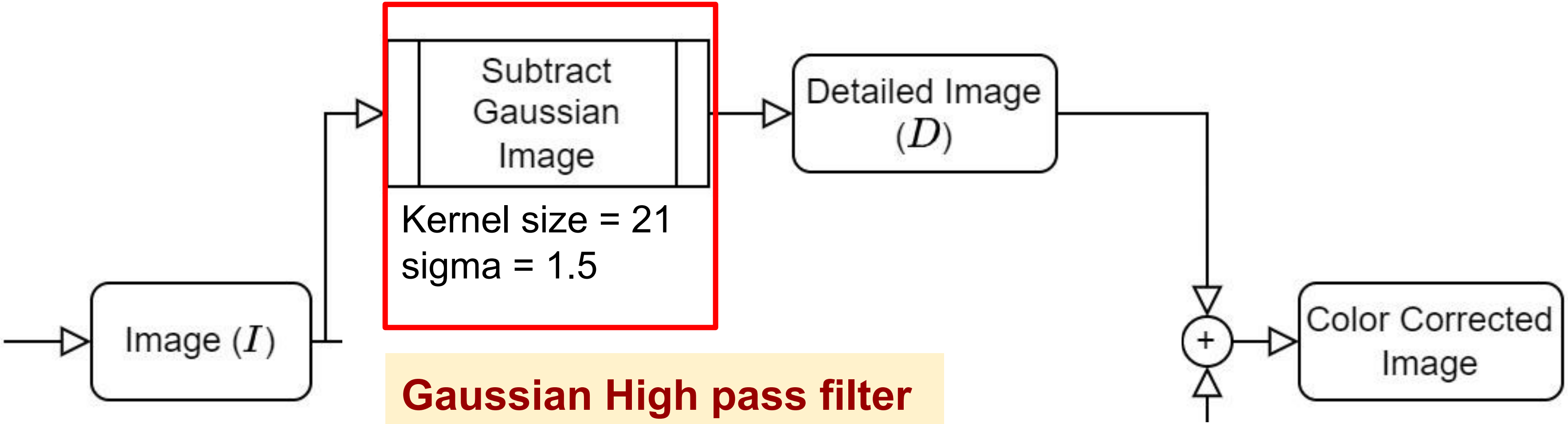
LACC-MAMGF



Subtract Gaussian Image
Detailed Image (D)
Image (I)
Compute Max Attenuation Map (A^M_{max})
$(1 - A^M_{max})I$
+
Color Corrected Image
Color Transfer Image (I^{CT})
$A^M_{max}I^{CT}$

LACC-MAMGF Implementation



Gaussian High pass filter

$$D_c = I_c - G_c * I_c$$

LACC-MAMGF Implementation

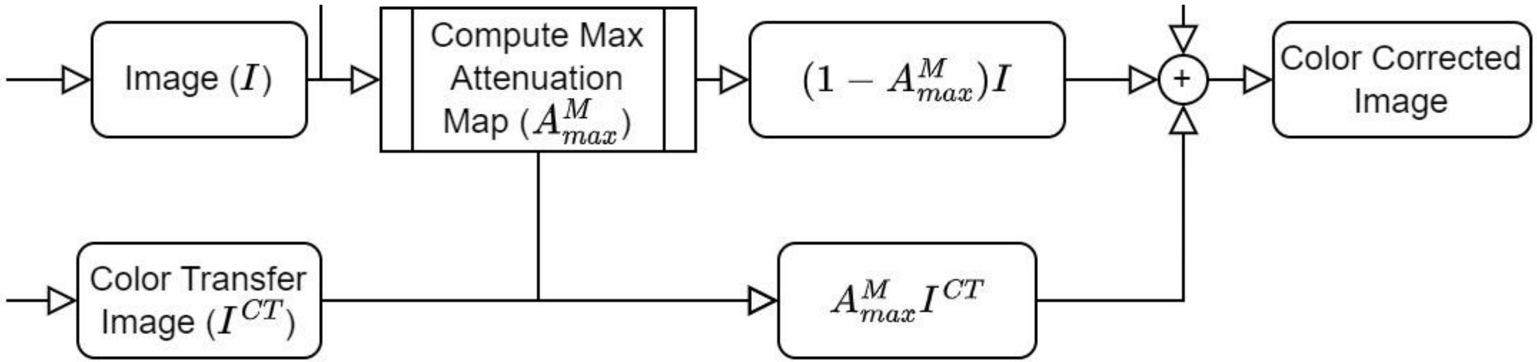
Original approach described in paper

$$A^M_{max} = \max\{1 - I_R^\gamma, 1 - I_G^\gamma, 1 - I_B^\gamma\}$$

Our approach

$$\boxed{A^M_{max}} = \max\{1 - (\boxed{\frac{I_R}{255}})^\gamma, 1 - (\boxed{\frac{I_G}{255}})^\gamma, 1 - (\boxed{\frac{I_B}{255}})^\gamma\} \quad \gamma = 1.2$$

The maximum **degree** of color attenuation (**should <1**)

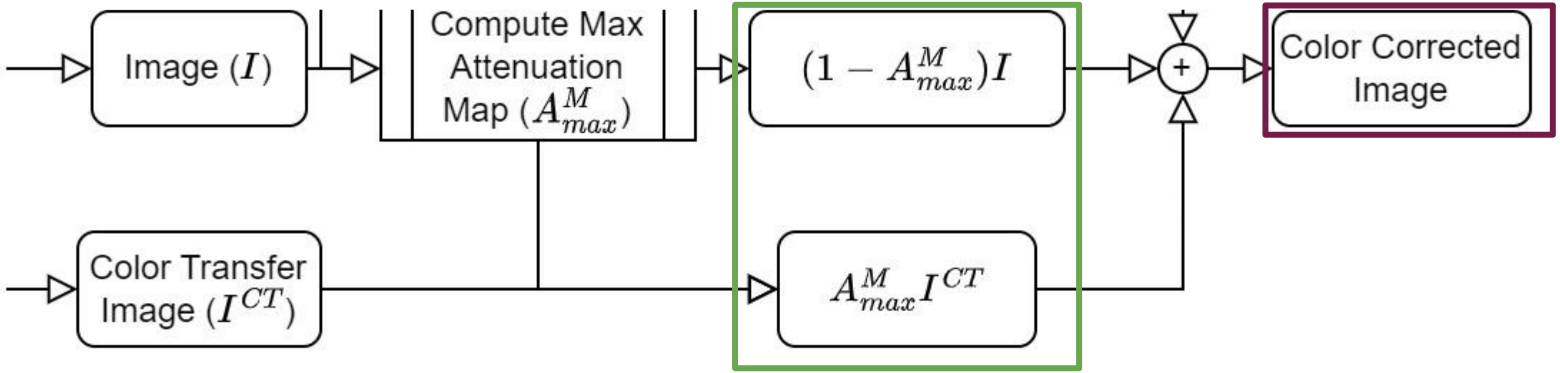


LACC-MAMGF Implementation

Rationales of modification

$$\boxed{I_c^{CC}} = D_c + \boxed{A_{max}^{M} I_c^{CT} + (1 - A_{max}^{M}) I_c}, c \in \{R, G, B\}$$

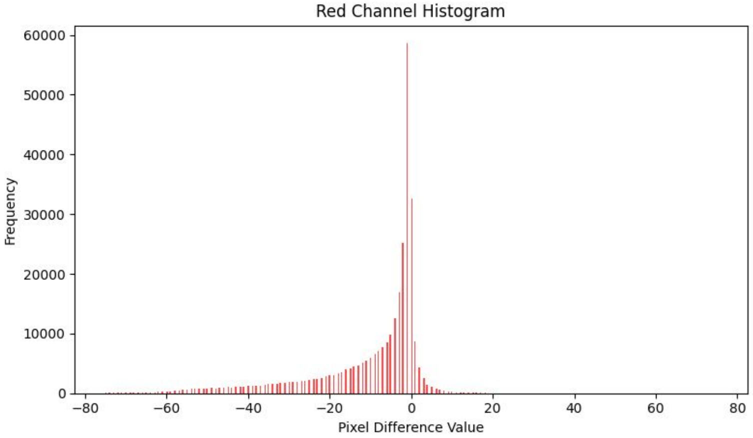
The **weighted average** of original and color transfer image



After MCLP

After MCLP+
MAMGF

Difference After MAMGF



After MCLP

reference image→

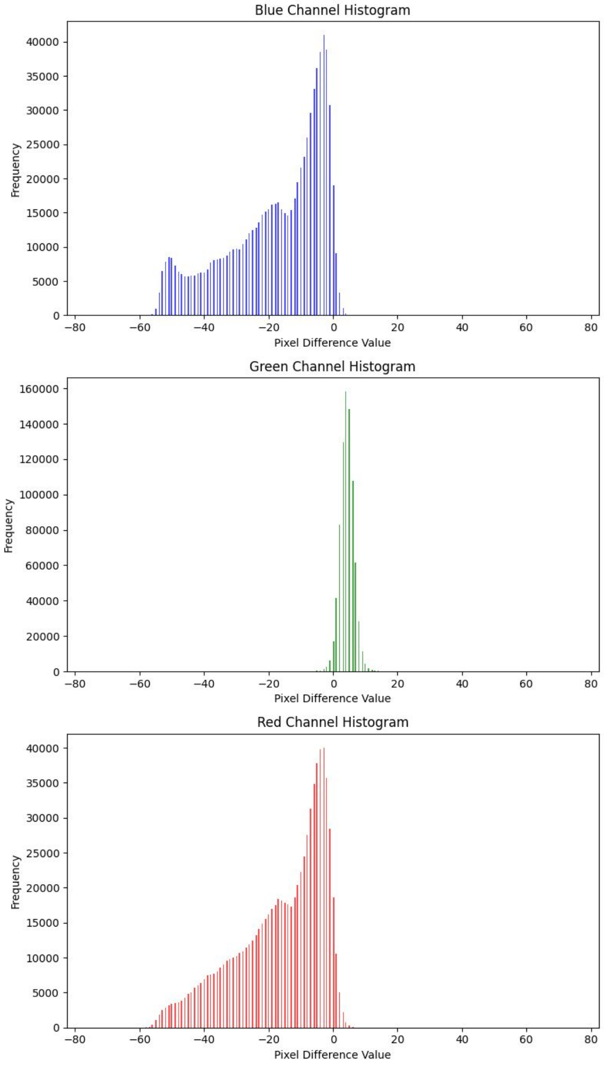
After MCLP+
MAMGF

Author’s result After
MCLP+MAMGF→

After MCLP

After MCLP+
MAMGF

Difference After MAMGF→



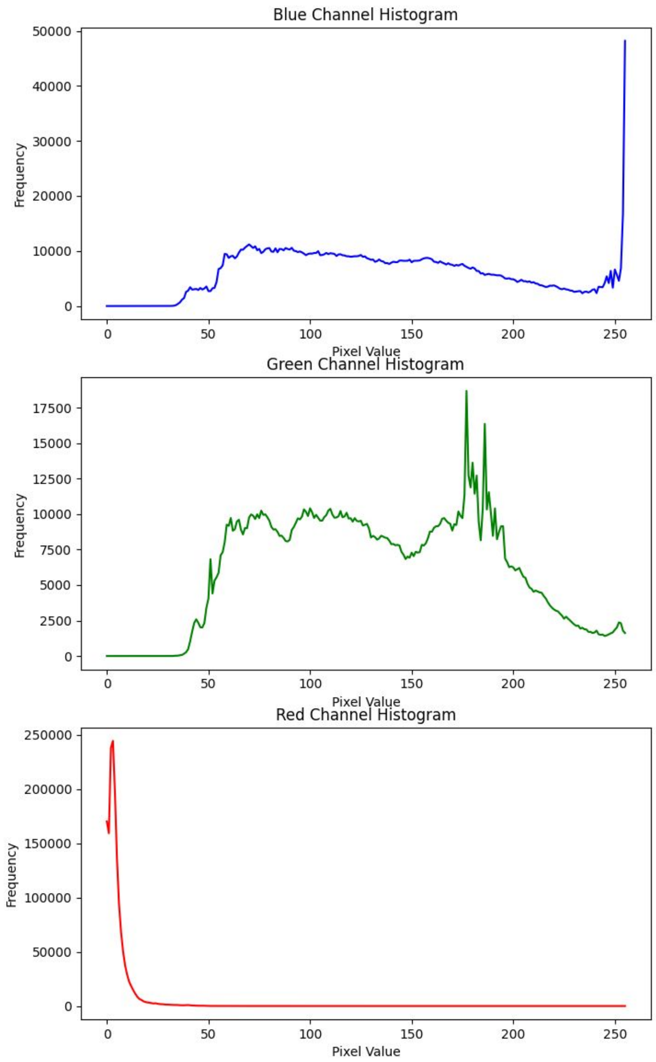
After MCLP

reference image→

After MCLP+
MAMGF

paper result After
MCLP+MAMGF→

Cases where LACC failed
(by both our and author’s method)



Cases where LACC failed
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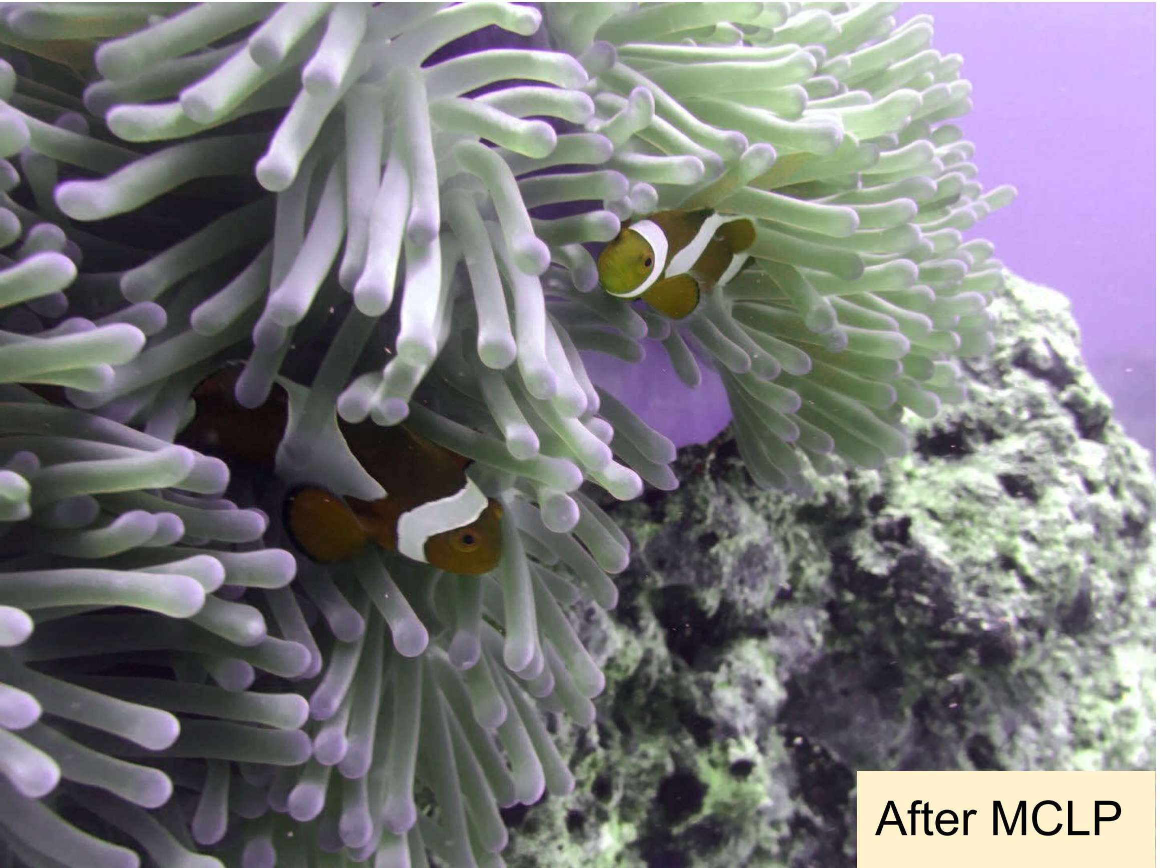
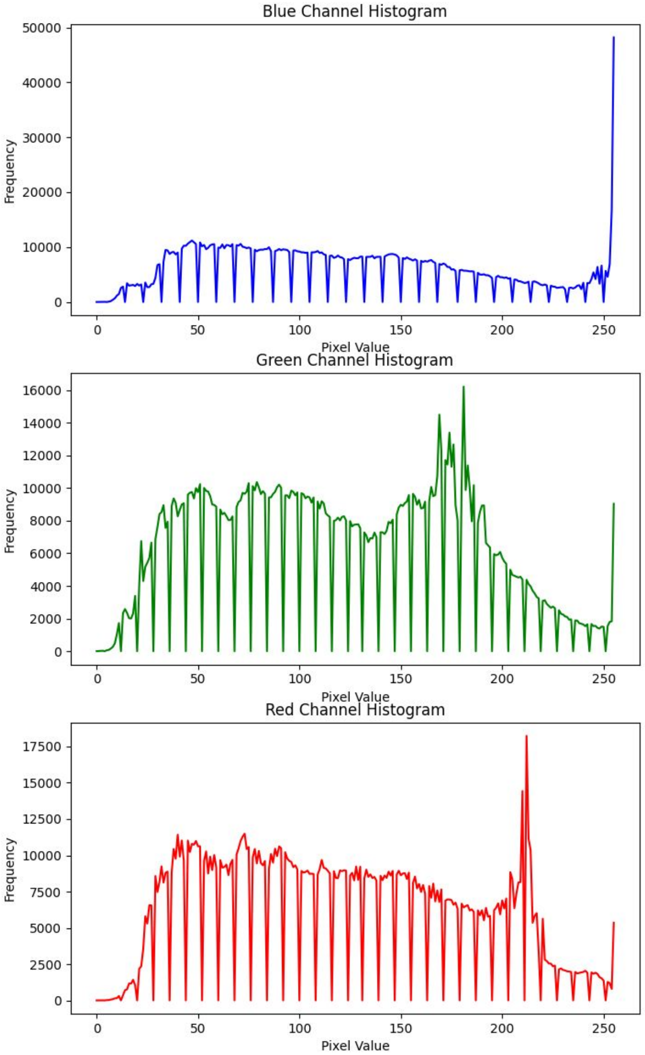
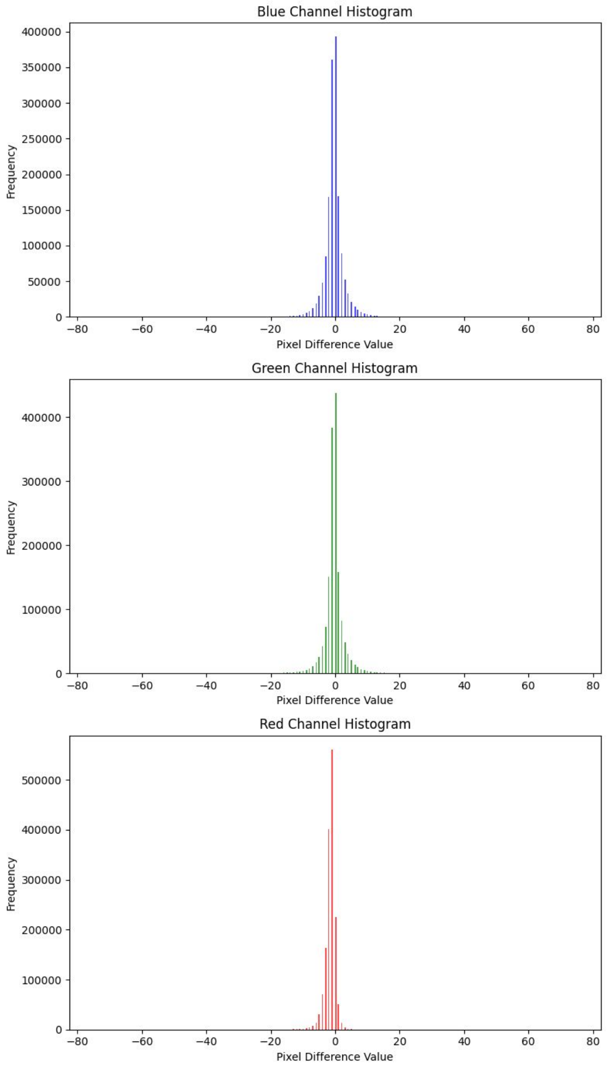




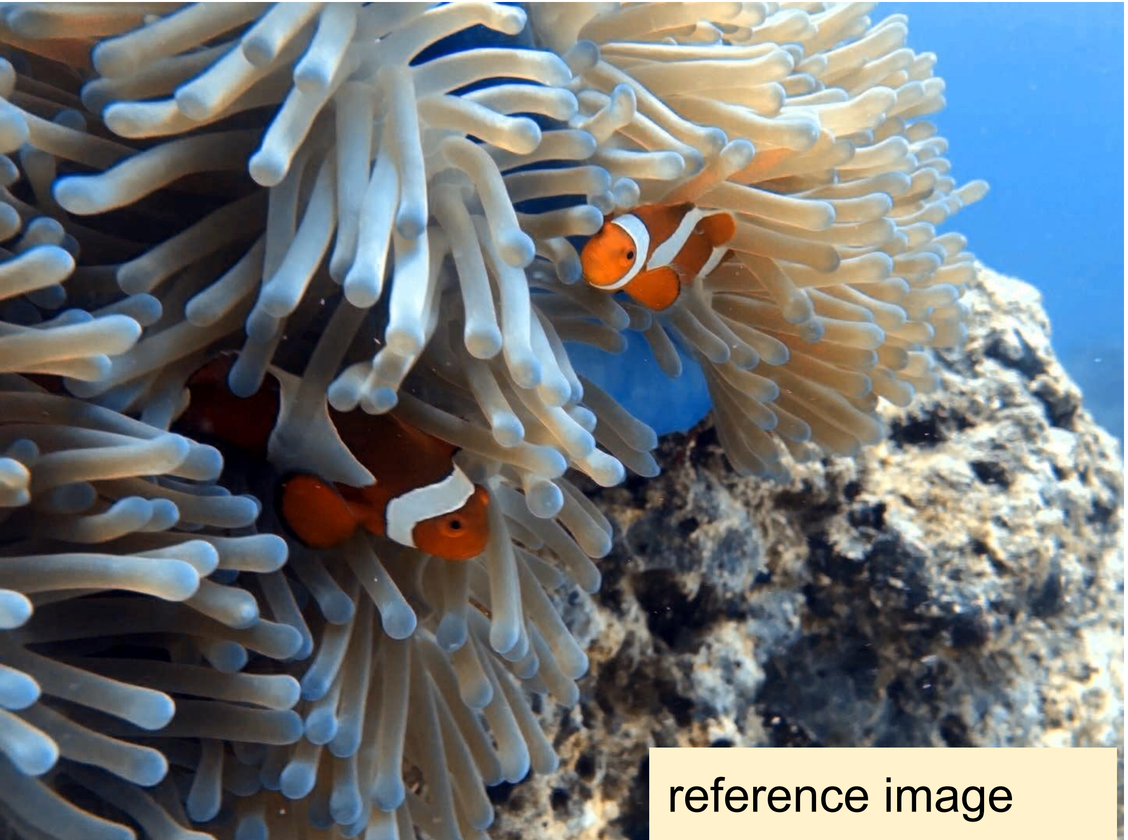
Cases where LACC failed
(by both our and author’s method)

After MAMGF

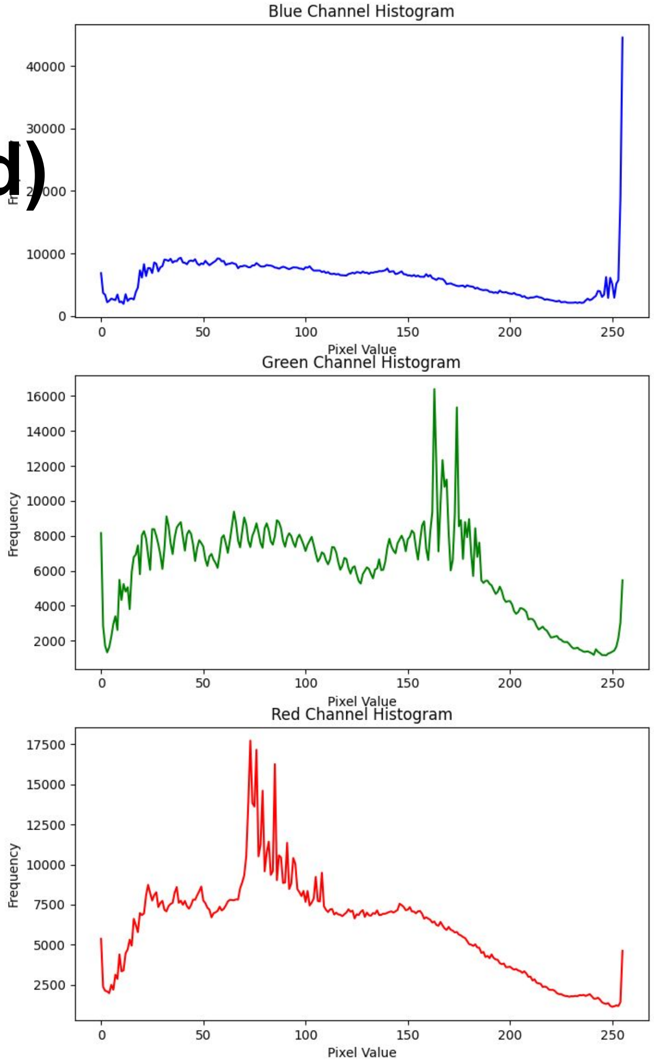
Difference After MAMGF→



Cases where LACC failed
(by both our and author's method)

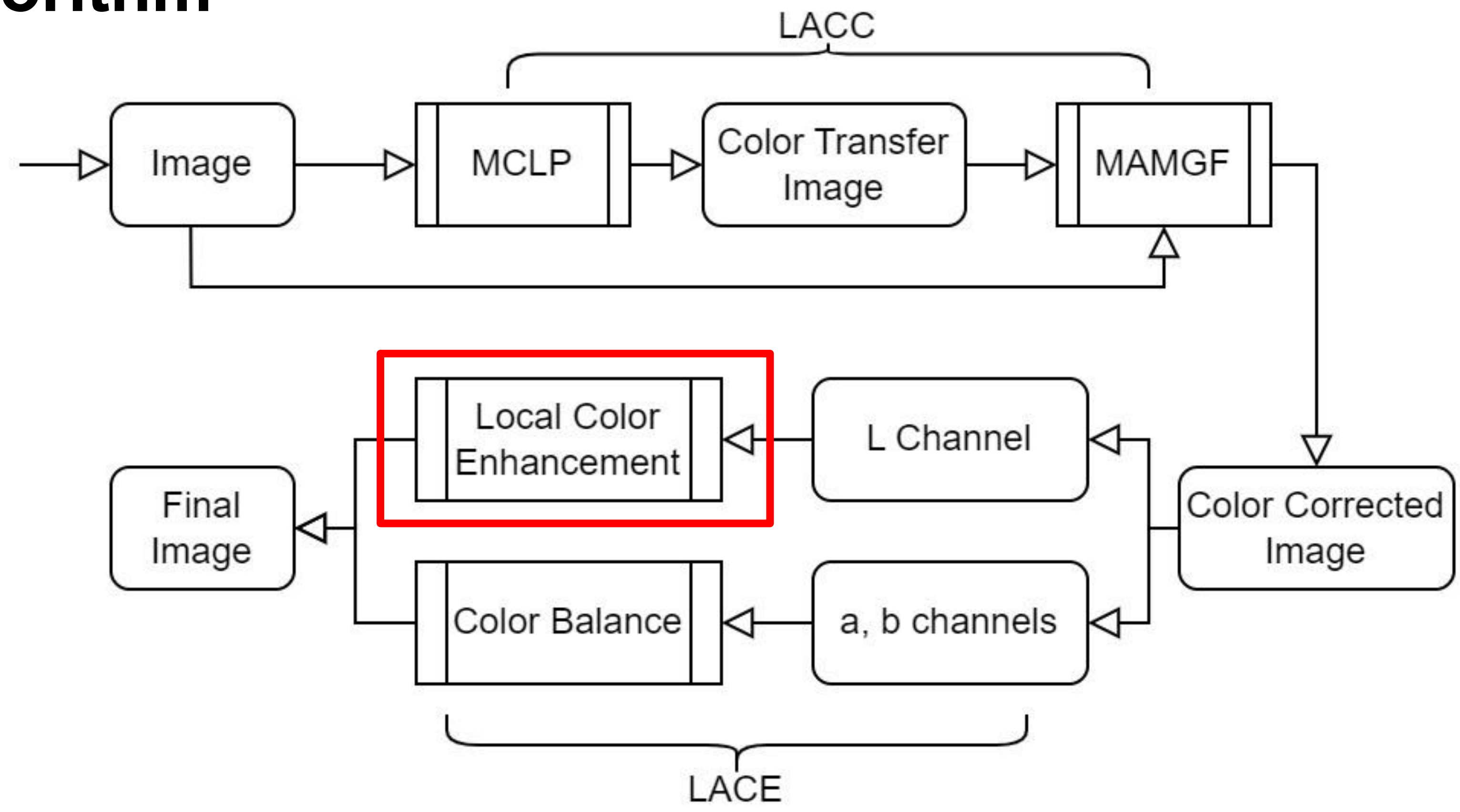


reference image



LACC performed well in both underwater and sandstorm dehazing

Algorithm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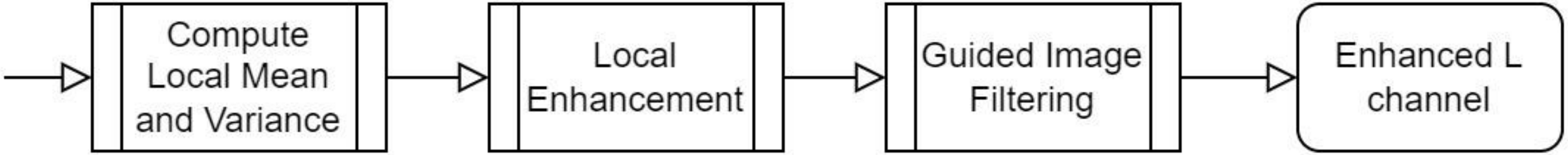
Color Corrected Image
Color Balance
a, b channels
LACE

LACE-Local Color Enhancement (LCE)



LACE- LCE Implementation

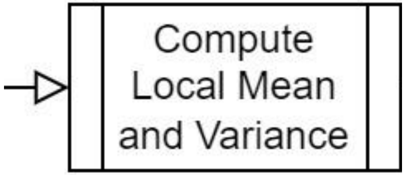
Input: L channel

- RGB to CIELAB
- Original range
  - L: 0~100
  - a, b: -128~127

Convert by cv2

- cv2 range
  - L, a, b: 0~255
- Scale or not?
  - Use cv2 range

LACE- LCE Implementation



$$u_B = \frac{\sum_{j=y}^{y+H-1} \sum_{i=x}^{x+W-1} L_B(i, j)}{HW},$$

$$\sigma_B = \frac{\sum_{j=y}^{y+H-1} \sum_{i=x}^{x+W-1} L_B(i, j)^2}{HW} - u_B^2,$$

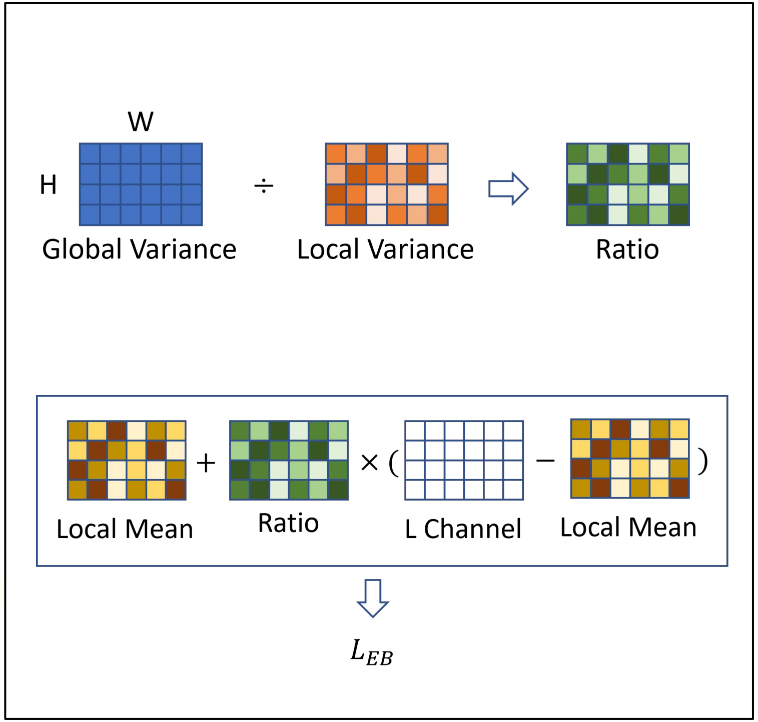
Different approaches

- Paper
  - summed area table
  - O(1) compute local mean and variance
- Our
  - 3D array
    w * h * window size
  - Compute local mean, variance, max, min
  - Faster

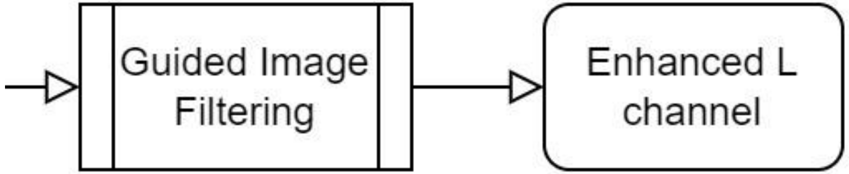
LACE- LCE Implementation

$$L_{EB}(i,j) = u_B + \boxed{\alpha}(L_B(i,j) - u_B),$$

$$\begin{cases} L_{EB}(i,j) = u_B + \boxed{\dfrac{\sigma_G}{\sigma_B}}(L_B(i,j) - u_B), \alpha < \beta \\ L_{EB}(i,j) = u_B + \beta(L_B(i,j) - u_B), \alpha \geq \beta. \end{cases}$$



LACE- LCE Implementation



$$\boxed{\kappa_B} = \frac{\frac{1}{HW}\sum_{(k,l)\in B} L^N_{EB}(k,l)\times L_{EB}(k,l) - \mu^N_{EB}(B)\times\mu_{EB}(B)}{\sigma^N_{EB}}$$

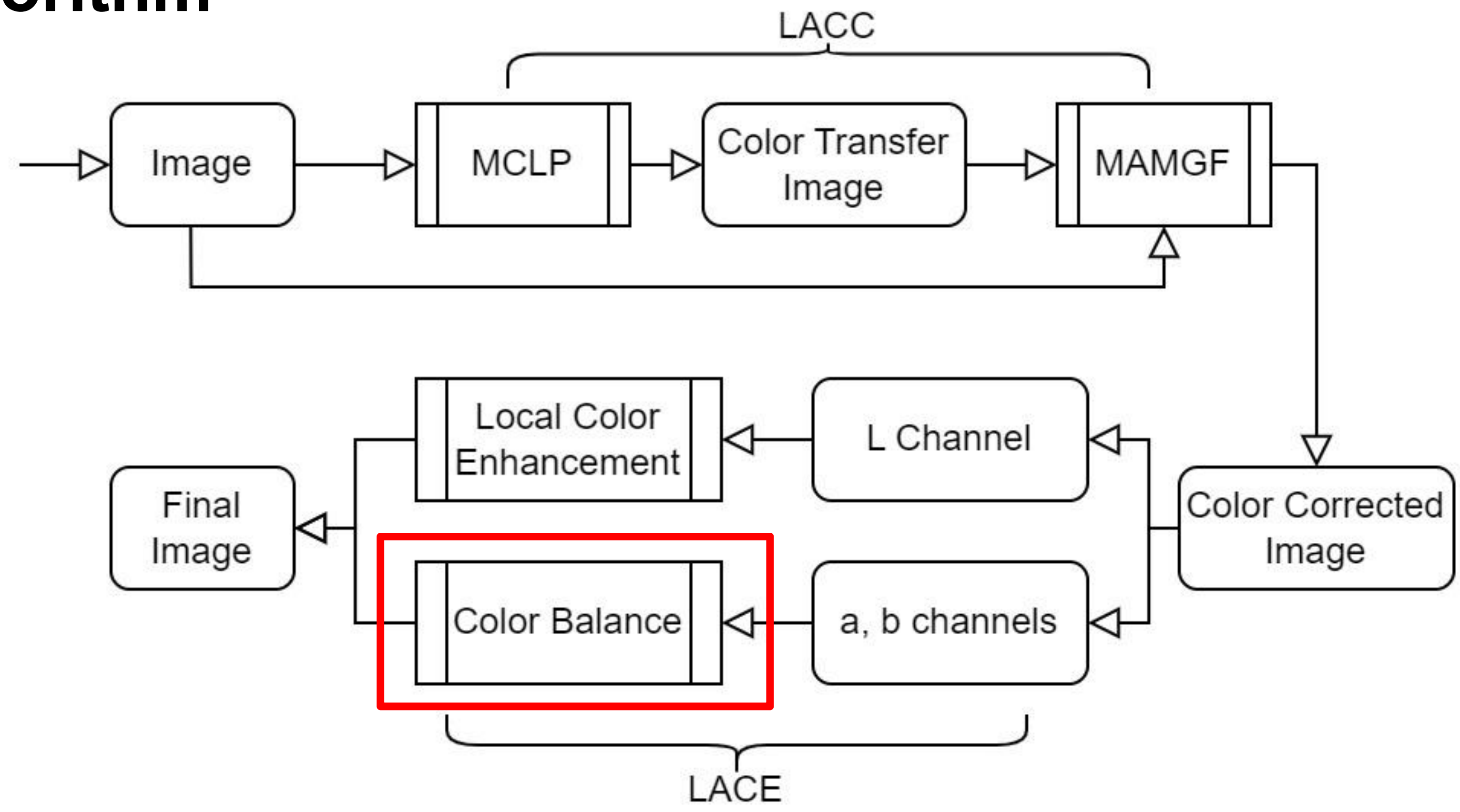
$$\boxed{\nu_B} = \mu_{EB}(B) - \kappa_B \times \mu^N_{EB}(B)$$

$$L^{gf}_{EB}(i,j) = \boxed{\kappa_{(i,j)}} L^N_{EB}(i,j) + \boxed{\nu_{(i,j)}}, \quad \forall (i,j)\in B(i,j),$$

Guided Image Filtering

- Preserve important details
  - smoothing out noise
  - remove unnecessary details
  - maintain the structure information

Algorithm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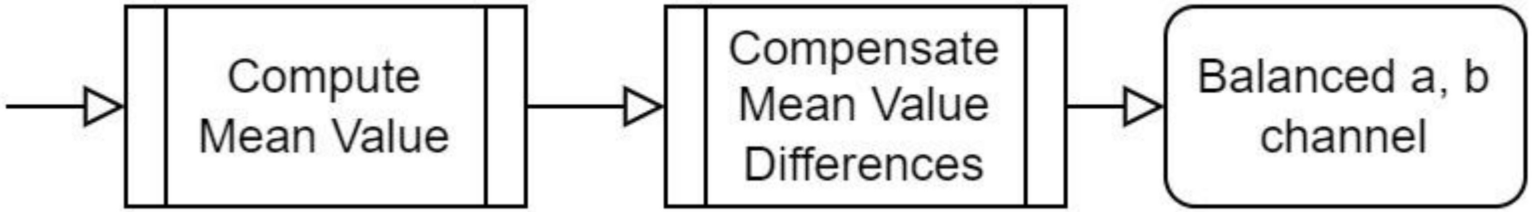
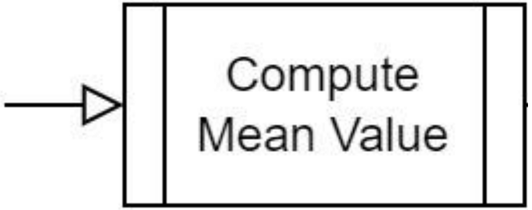
LACE-Color Balance (CB)

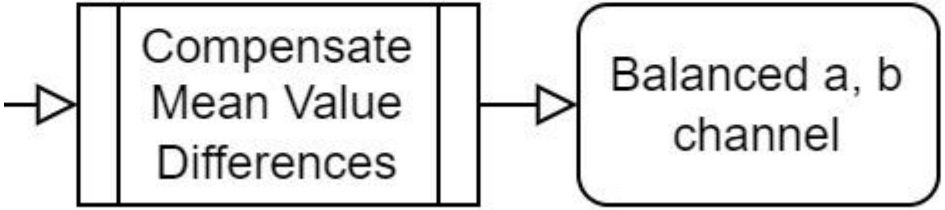


LACE- CB Implementation



$$\overline{I}_c = \frac{\sum_{i=1}^{H}\sum_{j=1}^{W} I_c(i, j)}{HW}, \quad c \in \{a, b\}.$$

LACE- CB Implementation



$$
\begin{cases}
I_{bc} = I_b + \dfrac{(\bar{I}_a - \bar{I}_b)}{(\bar{I}_a + \bar{I}_b)} I_b, \bar{I}_a > \bar{I}_b \\
I_{ac} = I_a + \dfrac{(\bar{I}_b - \bar{I}_a)}{(\bar{I}_b + \bar{I}_a)} I_a, \bar{I}_a < \bar{I}_b,
\end{cases}
$$

Change only one channel

- Mean a > Mean b
  - change b channel
- Mean b > Mean a
  - change a channel

LACE Implementation Result

Color Corrected Image

Result of LACE Operation

Results Comparison

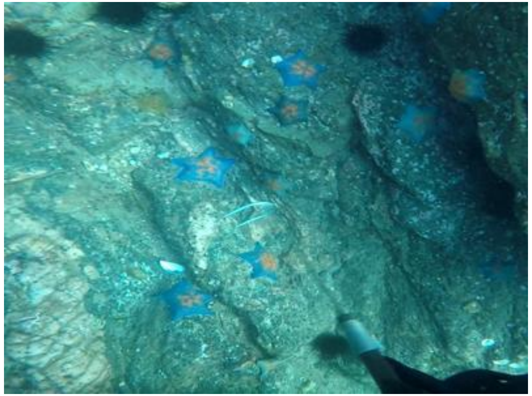
Data sets

- Underwater Color Cast Set (UCCS)
  - Color correction
- Underwater Image Quality Set (UIQS)
  - Enhance visibility
- Underwater Image Enhancement Benchmark (UIEB)
  - Robustness

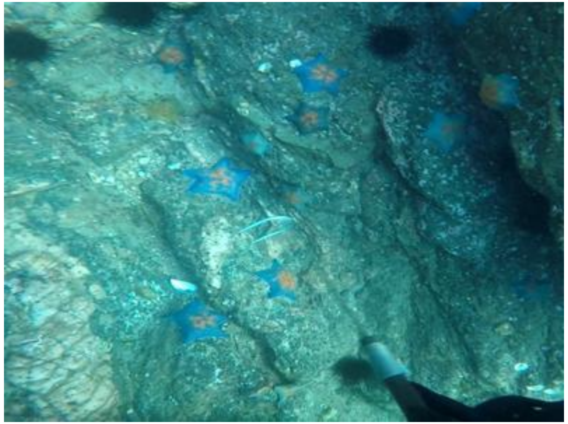
Results Comparison - UCCS

UCCS data set

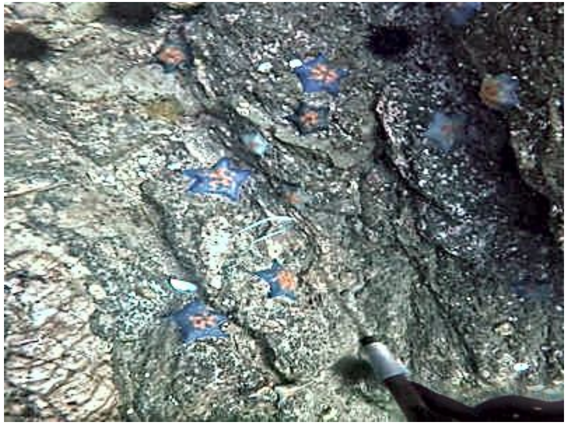
- evaluate the capability of different methods for color correction
- pictures in bluish, blue-green, and greenish tones



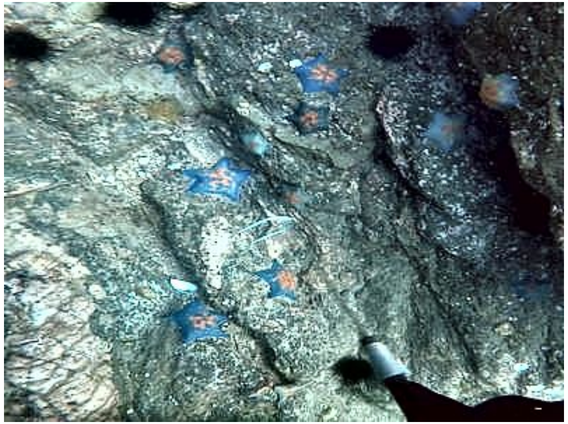
Results Comparison - UCCS (Blunish)



Input



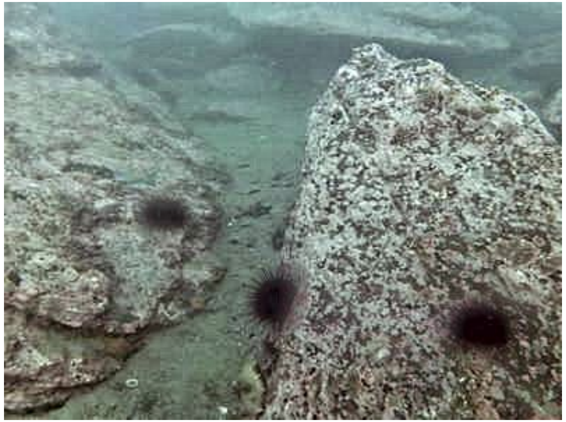
Our output



Paper’s output

Results Comparison - UCCS (Blue-Green)

Input



Our output

Paper’s output

Results Comparison - UCCS (Greenish)

Input

Our output

Paper’s output

Results Comparison - UIQS

UIQS data set

- evaluates the capability of different methods for enhancing the visibility of underwater images
- quality levels (in decreasing order): A, B, C, D, and E

Results Comparison - UIQS (A)

Input

Our output

Paper’s output

Results Comparison - UIQS (C)

Input

Our output

Paper’s output

Results Comparison - UIQS (E)

Input

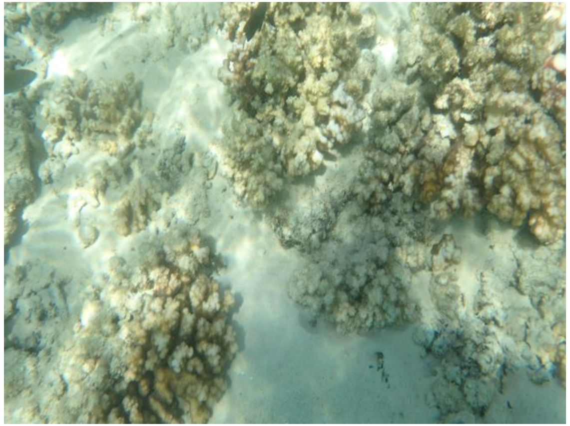
Our output

Paper’s output

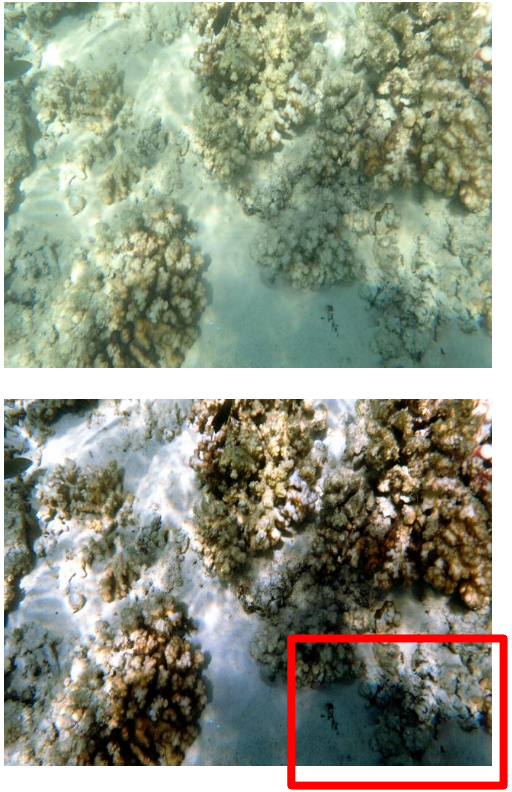
Results Comparison - UIEB

UIEB data set

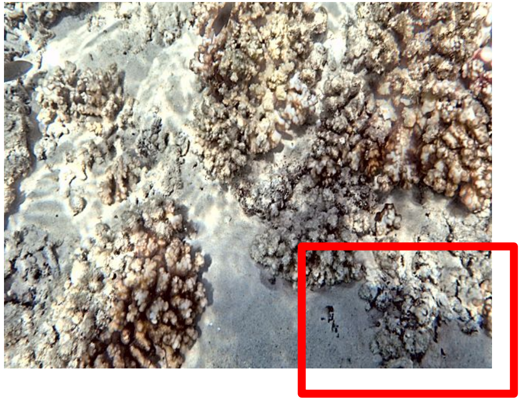
- evaluates the effectiveness and robustness of different methods for enhancing various underwater images
- reference images are provided



Results Comparison - UIEB (Low visibility)



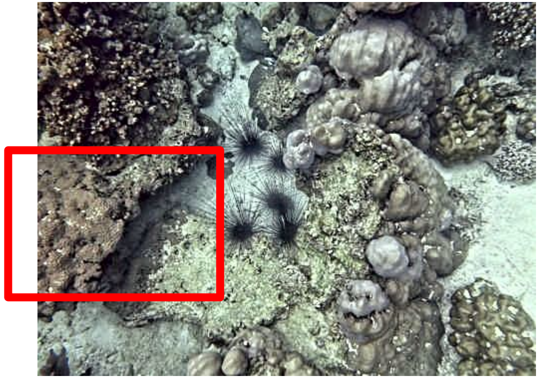
Input & Reference



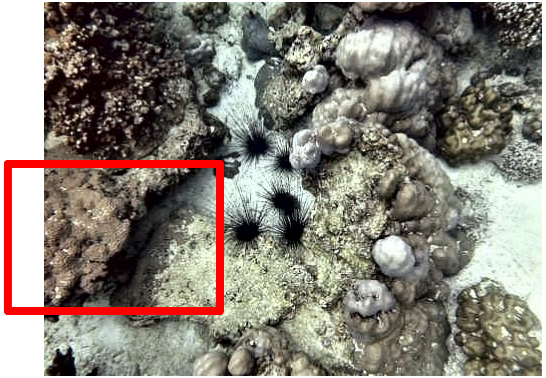
Our output

Paper's output

Results Comparison - UIEB (Hazzy)



Our output



Paper’s output

Input & Reference

What’s next?

- Improve the implementation
  - Current result is slightly greenish, lower contrast
- Provide quantitive evaluations
  - Adopt image quality evaluation metrics
  - Compare with paper results

Conclusion

The MLLE method provides:

- Color correction
- Contrast enhancement
- Efficient computation
- Generalization

Reference

- **Special thanks to Team 3 for implementation discussion**

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