A New Color Contrast Enhancement Algorithm for Robotic Applications

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Outline

• Motivation

• New Enhancement Method

• New Enhancement Measure

• Experimental Results and Analysis

• Conclusions and Future Work
Motivation

- Robots are used in varying fields of industry, military and security to assist and emulate human functions. Mobile cameras are the most widely used sensors in robot design and serve an important role in receiving signals and perceiving the outside world.

- It is straightforward for the human eye to perceive an image despite the presence of non-uniform illumination or colored light conditions.

- Unfortunately, the quality of images captured by the camera is not always satisfactory for robots. Thus, it can be a very complex task to respond rationally based on the perceived low quality image.
Motivation

- Quadratic filters have mainly been used for grayscale image enhancement and a preprocessing step for binarization*.

- Nonlinear filter has the ability to enhance contrast while simultaneously removing noise. Positive/Negative power law can be utilized in the filter design for further enhancing the desired portions*.

- Thus it is possible to apply the alpha weighted quadratic filter in color contrast enhancement.

Proposed Algorithm

Three major steps in the proposed color contrast enhancement algorithms.

(1) **Classification:**
   - Training set: 30 images from NASA dataset and Barnard dataset
   - Global logAMEE [0.1110, 0.1287] : dark image
   - Otherwise: bright image

(2) **Intensity Adjustment:** Adjust the global intensity
   - Dark image : Naka-Rushton function
   - Bright image: Power law

(3) **Color Contrast Enhancement:**
   - Alpha weighted quadratic filter
Algorithm Flowchart

Classification: If the modified logAMEE value belongs to [0.1110, 0.1287]

YES:
- Naka-Rushton intensity adjustment

NO:
- Power Law intensity adjustment

AWQF color contrast enhancement
Enhancement Measure

- The improvement in the enhanced images is often subjective and hard to measure.

- There is no universal measure specifying both the objective and the subjective validity of an enhancement method.

- However, there is a need of quantitatively measuring and evaluating the enhancement performance of an algorithm, especially when the algorithm is parametric.
  - to choose the best parameters;
  - to automate the image enhancement procedure

- Enhancement measure is usually based on contrast measure.

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**Enhancement Measure**

**logAMEE**

\[
\frac{1}{k_1 k_2} \times \sum_{k=1}^{k_1} \sum_{j=1}^{k_2} \left( \frac{I_{\text{max},k,j} \hat{\sim} I_{\text{min},k,j}}{I_{\text{min},k,j} \hat{\sim} I_{\text{max},k,j}} \right) \times \ln \left( \frac{I_{\text{max},k,j} \hat{\sim} I_{\text{min},k,j}}{I_{\text{min},k,j} \hat{\sim} I_{\text{max},k,j}} \right)
\]

Where an image is divided into \(k_1 \times k_2\) blocks. \(I_{\text{max};k,l}, I_{\text{min};k,l}\) are the maximum and minimum values of the pixels in each block separately. \(\hat{\sim}, \hat{\leq}, \hat{\geq}\) are PLIP operation

**Global logAMEE**

\[
\frac{1}{k_1 k_2} \times \sum_{k=1}^{k_1} \sum_{j=1}^{k_2} \left( \frac{I_{\text{max},k,j} \hat{\sim} I_{\text{min},k,j}}{I_{\text{min},k,j} \hat{\sim} I_{\text{max},k,j}} \right) \times \ln \left( \frac{I_{\text{max},k,j} \hat{\sim} I_{\text{min},k,j}}{I_{\text{min},k,j} \hat{\sim} I_{\text{max},k,j}} \right)
\]

This represents the ratio of the local Michelson contrast to the global Michelson contrast \(\frac{I_{\text{min},k,j} \hat{\sim} I_{\text{max},k,j}}{I_{\text{max},k,j} \hat{\sim} I_{\text{min},k,j}}\)
Intensity Adjustment

- **Naka-Rushton function:**
  
  \[ L_c(j, k) = \frac{I_c(j, k)}{I_c(j, k) + \beta H_c^*(j, k)} \times \frac{I_{c, max} + \beta H_c^*(j, k)}{I_{c, max}} \]

- **H_c^*(j, k) = HI_c(j, k)RS_c(j, k)**

- **HI_c(j, k) = I_c(j, k) \ast BF + [Y(j, k) + \text{const}] \bar{I_c}**

- **RS_c(j, k) = \begin{cases} 
  1 & \text{if } R I_c(j, k) S I_c(j, k) < 1 \\
  R I_c(j, k) S I_c(j, k) & \text{otherwise} \\
  2 & \text{if } R I_c(j, k) S I_c(j, k) > 2 
\end{cases}**

- **Chrominance correction:**  
  \[ R I_c(j, k) = \frac{Y(j, k)}{I_c(j, k)} \bar{I_c} \]

- **Contrast correction:**  
  \[ S I_c(j, k) = \frac{I_c(j, k) \ast BF}{I_c(j, k)} \]

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Quadratic Filter

• G. Ramponi [1990] proposed the idea of designing a quadratic filter particularly for image enhancement and preprocessing.

• By definition, the I/O relation of a quadratic filter can be expressed as the summation of linear component and quadratic component:

\[
y(n) = \sum_i w_1(i)x(n - i) + \sum_i \sum_j w_2(i, j)x(n - i)x(n - j)
\]

• Properties:
  - Symmetry
  - Isotropism
  - Ensuring that the summation of the linear coefficients is one and that the coefficient of the quadratic term is zero
Alpha Weighted Quadratic Filter

The proposed quadratic filter for edge detection is composed of the sum of two terms:

\[ y(x) = y_0(x) + y_1(x) \]

\( y_0 \) is designed as an edge preserving nonlinear smoother. It performs a smoothing operation on the input features having low amplitude (zero mean noise) and a sharpening operation on significant details: remove noise while minimizing the blurring of edges.

\[ y_0 = h_0 x_0 + h_1 (x_1 + x_3 + x_5 + x_7)^a + h_2 (x_2 + x_4 + x_6 + x_8)^b \]
\[ + w_0 x_0^2c + w_1 (x_1^2 + x_3^2 + x_5^2 + x_7^2)^d + w_2 (x_2^2 + x_4^2 + x_6^2 + x_8^2)^e \]

\( y_1 \) deals with neighboring pixels to detect edges. Detecting the presence of correlated details (edges)

\[ y_1 = s_1 (x_0 x_1 + x_0 x_3 + x_0 x_5 + x_0 x_7)^f + s_2 (x_0 x_2 + x_0 x_4 + x_0 x_6 + x_0 x_8)^g + \]
\[ r_1 (x_1 x_2 + x_3 x_4 + x_5 x_6 + x_7 x_8 + x_1 x_8 + x_3 x_2 + x_5 x_4 + x_7 x_6)^h + \]
\[ r_2 (x_2 x_8 + x_4 x_2 + x_6 x_4 + x_8 x_6)^i \]
Experiment Results (1)

Unsatisfied illumination:
1. Underexposure: need to recover color and details

2. Strong sunlight: retain details in the shadow
Application 1: Robotic surgery

- Medical images are always of low contrast and poor resolution, due to the limitations of the hardware system or limitations on allowable exposure time.
- In robotic surgery, the surgeon uses either a direct telemanipulator or computer control to operate the instrument movement. Thus the image captured by the robot camera is required to truly and precisely reflect the real position of organs and vessels.
Experiment Results (3)

Application 2: aerial cameras captured image
- The presence of the atmospheric layer may cause blurring effects on the image
- This type of image contains many low contrast and dark areas
- Need to reveal the extent of the sediment outwash
- More details are recovered and more vivid color is shown with the proposed method
Experiment Results (4)

Comparison of the effect of the alpha power in filter design

Original Image

Enhanced image w/o alpha power

Enhanced image w/alpha power
Experiment Results (5)

Parameter selection/enhancement quality measure:
Color enhancing results based on different parameter c
Experiment Results (6)

Parameter selection/enhancement quality measure:
Color enhancing results based on different parameter c and d

Original Image

AWQF enhancement with c= 1.6, d=1.4

AWQF enhancement with c= 1.9, d=1.4

AWQF enhancement with c= 2.0, d=1.5

Average results

Global logAMEE
Conclusions and Future Work

• A new Alpha Weighted Quadratic Filter based color contrast enhancement method was introduced.

• A new Global logAMEE measure was shown to quantitatively evaluate the enhancement performance and automatically select parameters.

• Compared to the Retinex algorithm, the AWQF based algorithm provides better local contrast. Compared to the Wang’s algorithm, the AWQF based algorithm achieved better color enhancement.

• The algorithm is simple and efficient and can be used for automatic robot vision applications.

• New color correction methods will be incorporated to the current method. The new measure will also be tested for different image databases.