Innovative Color Interpolation Using Fuzzy Logic and Linear Regression

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Abstract

Fuzzy logic and linear regression method

- The Fuzzy logic method
  - Based on the effect between pixels
    - To avoid color distortion around the edges
- The linear regression method
  - To process the interaction effect among R, G and B channels
  - To eliminate false color, color moire, aliasing and color shift in the full color camera output
- To show a very good quality
Introduction

Fig. 1  Bayer pattern CFA and interpolation process
Fig. 2 An example of a color image and its Bayer pattern CFA image

(a) Color image  (b) Bayer pattern CFA image

Fig. 3 An example of an image with artifacts caused by CFA interpolation

(a) Original image  (b) Interpolated image
FLLRM algorithm

- To improve the quality of interpolated images
- To reduce the estimation errors
- To improve the G channels of interpolated images
  - Using fuzzy logic method to reduce the edge distortion between the pixels of G channels
  - The linear regression method to find the relationships between R, G, and B channels
- To modify some missing R and G channels
  - Using fuzzy logic method
G channel interpolation

- Using the Pei and Tam method
  - The good performance and simplicity
- Using the correlation between R and G channels

\[ K_R = G - R \]  \hspace{1cm} (1)

\[ K_B = G - B \]  \hspace{1cm} (2)

\[ G7 = R7 + \frac{(K_R 3 + K_R 6 + K_R 8 + K_R 11)}{4} \]  \hspace{1cm} (3)

- \( K_R 3 = G3 - R3 = G3 - (R1 + R7)/2 \)
- \( K_R 6 = G6 - R6 = G6 - (R5 + R7)/2 \)
- \( K_R 8 = G8 - R8 = G8 - (R7 + R9)/2 \)
- \( K_R 11 = G11 - R11 = G11 - (R7 + R13)/2 \)
R channel and B channel interpolation

\[
R3 = G3 + \frac{(K_R 1 + K_R 7)}{2}
\]  \hspace{1cm} (4)

\[
B7 = G7 + \frac{(K_B 2 + K_B 4 + K_B 10 + K_B 12)}{4}
\]  \hspace{1cm} (5)

Fig. 4 An example of Bayer pattern
Color Improvement of Interpolated Color Filter Array Image Using FLLRM

![Diagram showing the process of improving interpolated CFA images using fuzzy logic and linear regression.]

Fig. 5 The improving process of interpolated CFA images
G channel interpolation

- To determine the $G_i$ input membership function and G value output membership function
  - Using fuzzy logic method
  - The input membership function
    - High: $G_i > 192$
    - Low: $G_i < 64$
  - The output membership function
    - High: $G_i > 192$
    - Low: $G_i < 64$
    - Medium: $G_i = 128$
Fig. 6 An example for fuzzy logic pattern

(a) Input membership function

(b) Output membership function

Fig. 7 Membership function
Table 1. The Fuzzy Rules

<table>
<thead>
<tr>
<th>Rule</th>
<th>G₁</th>
<th>G₂</th>
<th>G₃</th>
<th>G₄</th>
<th>G</th>
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</table>

- If part: And method
- Then part: Cut method
- The between rule: Or method
- The defuzzification: Center-of-Area method
To modify R and B

- Using linear regression

\[ G = m_0 R + m_1 B + m_2 \]  

where \( m_0, m_1, m_2 \) : linear regression elements

- An estimate G value

\[ G_e = \begin{bmatrix} R \\ B \\ 1 \end{bmatrix} \]  

(7)
To optimize the estimated G values
- Defined the mean square error

\[ Cost \_ G(m_j \mid j = 0 \sim 2) = \sum_{i=1}^{n} (G(i) - Ge(i))^2 \]  \hspace{1cm} (8)

where \( G(i) \): original value of G channel for i-th color patch
\( Ge(i) \): estimated value of G channel for i-th color patch
\( m_j \): element of the matrix

- To fine the minimum of the cost function

\[ \frac{\partial Cost \_ G(m_j)}{\partial m_j} = 0 \]  \hspace{1cm} (9)
– The matrix element

\[
[m_0 \; m_1 \; m_2]^T = A_{3\times3}^{-1} B_{3\times1}
\]  \quad (10)

- The matrix A and B

\[
a(i, j) = \sum_{l=1}^{n} c_i(l) \cdot c_j(l) \quad (11)
\]

\[
b(i) = \sum_{l=1}^{n} G(i) \cdot c_i(l) \quad (12)
\]

where \( c_0 \sim c_2 \) : input coefficient

\( m_0 \sim m_2 \): element of matrix

\( G(i) \) : original G value of i-th color patch
- To obtain R channel and B channel

\[ R = \frac{(G - m_1 B - m_2)}{m_0} \quad (13) \quad B = \frac{(G - m_0 R - m_2)}{m_1} \quad (14) \]
To obtain RGB value of the whole images
- The modified R and B channel
  - Using fuzzy logic method

Fig. 10 The result of modified B channel
Experimental Results

- The major components of the platform
  - ITRI digital camera system

Table 2. Component

<table>
<thead>
<tr>
<th>Num.</th>
<th>Component</th>
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<tbody>
<tr>
<td>1</td>
<td>4 Mega Pixels CCD</td>
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<tr>
<td>2</td>
<td>ARM9EJ-S 175 MHz core</td>
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<tr>
<td>3</td>
<td>16K I-cache, 16K D-cache</td>
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<td>4</td>
<td>On-chip 16K RAM and 8K ROM</td>
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<td>5</td>
<td>108 MHz up to 256MB SDRAM</td>
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<td>6</td>
<td>2 SDRAM DMA channels</td>
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Fig. 11 The hardware Architecture of digital camera platform
Find the relationship between R, G, and B channel

- The relationship among R, G, and B channel

\[ G_e = m_0 R + m_1 B + m_2 \]

\[ G_e = 0.39R + 0.665B - 6.114 \]

Fig. 12 The CFA image of GretagMacbeth ColorChecker
Table 3. Experiment Result

<table>
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<tr>
<th>Num.</th>
<th>R, G, B</th>
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Fig. 13 The difference value ($\Delta G$) between G and $G_e$
◆ Result

(a) Result of FLLRM

(b) Result of P&T

Fig. 14 Aperture Resolution chart

(a) Result of FLLRM

(b) Result of P&T

Fig. 15 EIAJ Test chart-B2
Fig. 16 EIAJ Test chart-1

(a) Result of FLLRM  (b) Result of P&T

Fig. 17 Resolution chart (In Mega Cycle)

(a) Result of FLLRM  (b) Result of P&T

Fig. 18 Half-tone Resolution chart
Conclusions

- The developed algorithm
  - To improve the interpolation colors CFA images
  - Using fuzzy logic method
    - To avoid color distortion around edges
  - Using linear regression method
    - To optimize the interaction effect among R, G and B channel
  - To eliminate false color, color moire, aliasing and color shifts
  - A very good performance