Demosaicing with Improved Edge Direction Detection

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Overview

• Demosaicing Background
• Basics and Challenges
• Advanced Methods (State of the Art)
• Color Channel Reconstruction
• Conclusion
Demosaicing Background

Why Image Reconstruction?

- Incomplete color planes from CCD sensors.

Color Filter Array (CFA) on image sensor.
Basics and Challenges

Color Plane Interpolation

- Must Interpolate color planes to re-create image.

Red Channel Interpolation
Basics and Challenges

Color Plane Interpolation Methods

- **Pixel Averaging**
  - lose image resolution

- **Nearest Neighbor**
  - Poorest Quality

- **Bilinear/Spline**
  - Color artifacts at edges
Basics and Challenges

Color Artifacts

- Problem with most simple interpolation algorithms is the presence of color artifacts.

Original Image

Bilinear Interpolation of Bayer Image
Background

Basics

Advanced Methods

Channel Reconstruction

Conclusion

**Basics and Challenges**

**Color Artifacts**

- Due to interpolation across edges.

![Diagram showing color artifacts due to bilinear interpolation](image)

**Dark to Light Edge over Bayer Pattern**

**Resulting Edge after Interpolation**

**Artifacts**

**Bilinear Interpolation**
Advanced Techniques for Color Plane Interpolation

- Use color plane gradients
- Group pixels of similar objects
- Interpolate along edges (not across)
- Interpolate green color plane first
- Interpolate image more than one iteration (refinement)
Advanced Methods

Using Gradients for Image Reconstruction

- Better estimation of color plane behavior.

\[
D_x(P5) = \frac{P4 - P6}{2} \\
D_y(P5) = \frac{P2 - P8}{2} \\
D_{xd}(P5) = \frac{P3 - P7}{2\sqrt{2}} \\
D_{yd}(P5) = \frac{P1 - P9}{2\sqrt{2}}
\]

Notice that the differences are always from the same color plane.

Bayer Pattern for Green Centered Pixel

1. GRADIENTS
Kimmels ‘E’ Function for Pixel Grouping

- Associates colors of the same object.

If P5 and Pi are part of the same object, E will be close to unity.

\[ E_i(P5) = \frac{1}{\sqrt{1 + Di(P5)^2 + Di(Pi)^2}} \]

There are eight Ei values for each pixel. One for each neighbor.

Bayer Pattern for Green Centered Pixel

1. GRADIENTS
2. GROUPING
Interpolation is best performed in the same direction as an edge.

Edge detection of radius 3

\[
\Delta H_G(P13) = |P12_G - P14_G|
\]

\[
\Delta V_G(P13) = |P8_G - P18_G|
\]

\[
\Delta H_R(P13) = |P11_R + P15_R - 2 \times P13_R|
\]

\[
\Delta V_R(P13) = |P3_R + P23_R - 2 \times P13_R|
\]
Advanced Methods

Narrow Edge Detection

- Uses narrow edge detection to improve edges by looking between color planes.

**Edge detection of radius 2**

\[ \Delta H_{GR}(P13) = \left| P12_G + P14_G - 2P13_R \right| \]
\[ \Delta V_{GR}(P13) = \left| P2_G + P8_G - 2P13_R \right| \]
\[ \Delta H_{GB}(P13) = \frac{1}{2} \left( \left| P7_B + P9_B - 2P8_G \right| + \left| P17_B + P19_B - 2P18_B \right| \right) \]
\[ \Delta V_{GB}(P13) = \frac{1}{2} \left( \left| P7_B + P17_B - 2P12_G \right| + \left| P9_B + P19_B - 2P14_B \right| \right) \]
Advanced Methods

Local Inter-Channel Correlation

- Compare average color differences in a 5x5 region to determine whether the Red or Blue channel is more closely related to the green.

\[ C_{GR} = |\overline{G}_{5x5} - \overline{R}_{5x5}| \]

\[ C_{GB} = |\overline{G}_{5x5} - \overline{B}_{5x5}| \]

Bayer Pattern for Red
Centered Pixel
Advanced Methods

Improved Edge Detector

Now we can complete the edge detector

\[ \Delta H = \Delta H_R + \Delta H_G + \begin{cases} \Delta H_{GR} & \text{if } C_{GR} \leq C_{GB} \\ \Delta H_{GB} & \text{otherwise} \end{cases} \]

\[ \Delta V = \Delta V_R + \Delta V_G + \begin{cases} \Delta V_{GR} & \text{if } C_{GR} \leq C_{GB} \\ \Delta V_{GB} & \text{otherwise} \end{cases} \]
Channel Reconstruction

Channel Reconstruction Overview

• For each pixel we now have: $E_i(P_i) \Delta H \Delta V$

• Approximate the red and blue channels using Bilinear Interpolation.

• Reconstruct the green channel using edge detectors and the approximated red and blue.

• Reconstruct the red and blue channels using the complete green channel.

1. GRADIENTS

2. GROUPING

3. EDGE DETECT 3 pxls

4. EDGE DETECT 2 pxls

5. COLOR CORRELATION

6. IMPROVED EDGE DETECTION
Channel Reconstruction

Green Channel Reconstruction

• For each Green pixel on a red center...

\[
P_{13G} = P_{13R} + \begin{cases} 
E_{P2} (P_{12G} - P_{12R}) + E_{P4} (P_{14G} - P_{14R}) & \text{if } \Delta H > \Delta V \\
E_{P8} (P_{8G} - P_{8R}) + E_{P18} (P_{18G} - P_{18R}) & \text{if } \Delta H < \Delta V \\
\sum_{i=8,12,14,18} E_{Pi} & \text{otherwise}
\end{cases}
\]

• A similar approach is taken to the finding the green value at a blue centered pixel

Bayer Pattern for Red Centered Pixel

1. GRADIENTS
2. GROUPING
3. EDGE DETECT 3 pxls
4. EDGE DETECT 2 pxls
5. COLOR CORRELATION
6. IMPROVED EDGE DETECTION
Channel Reconstruction

Blue and Red Channel Reconstruction

- Blue and red channels are then completed using the full green channel.

P13_B = P13_G + \frac{E7 \cdot K7 + E9 \cdot K9 + E17 \cdot K17 + E19 \cdot K19}{E7 + E9 + E17 + E19}

Where… \( K_i = P_{iB} - P_{iG} \)

Similar approach is taken for completing Red channel.
Conclusion

• Highly computational and hence slow.
• Not suitable for real-time applications.
• Drastically reduces color artifacts.
• Improved Edge Quality.

Thank You
References

