Demosaicing with Improved Edge Direction Detection

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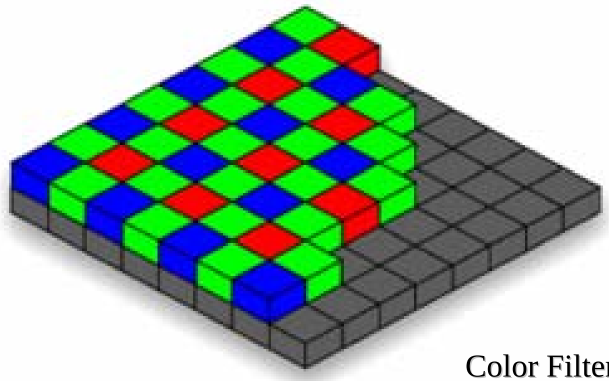
Overview

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

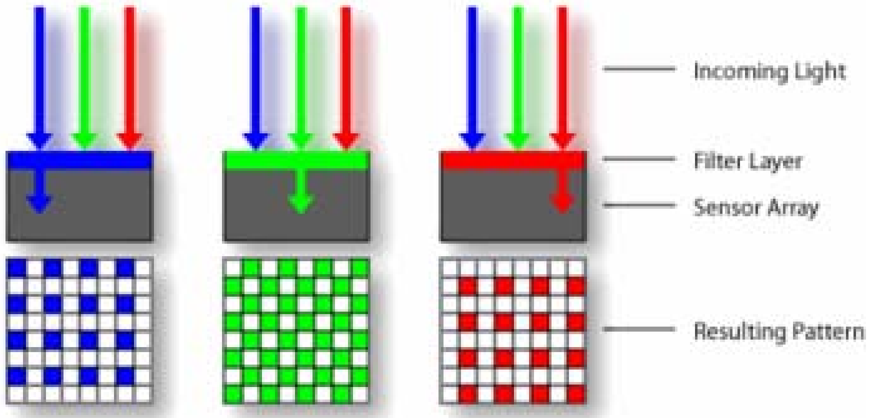
Demosaicing Background

Why Image Reconstruction?

- Incomplete color planes from CCD sensors.



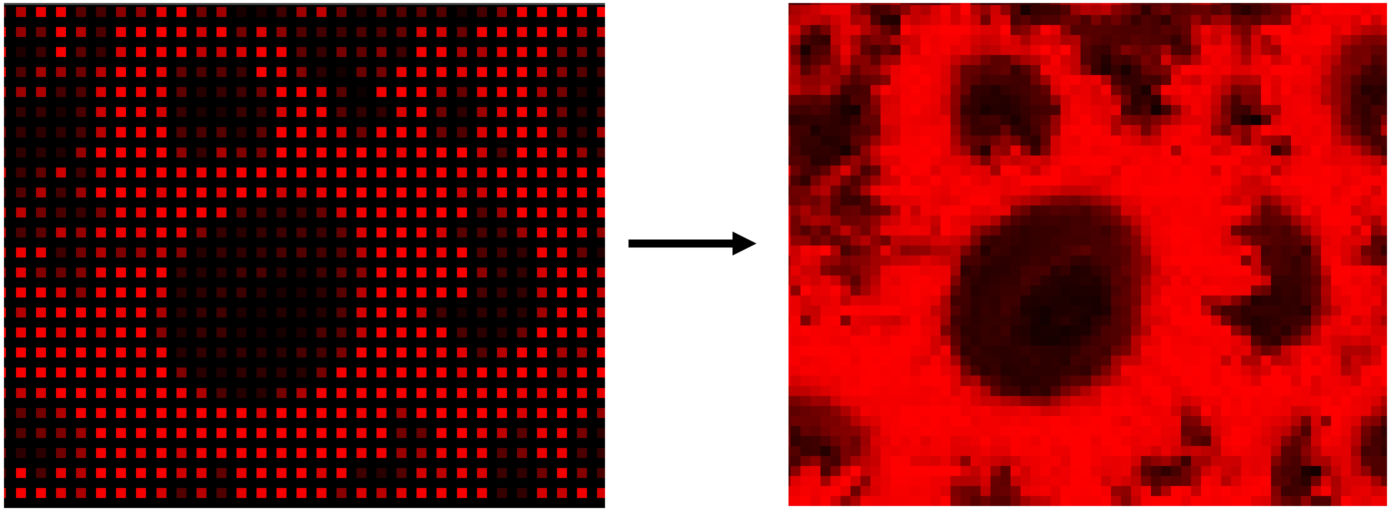
Color Filter Array (CFA) on image sensor.



Basics and Challenges

Color Plane Interpolation

- Must Interpolate color planes to re-create image.



Red Channel Interpolation

Basics and Challenges

Background

Basics

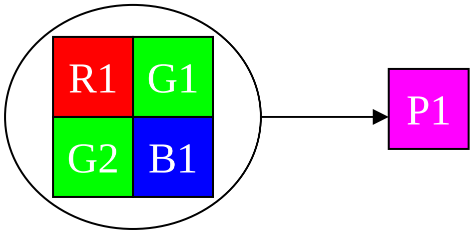
Advanced Methods

Channel Reconstruction

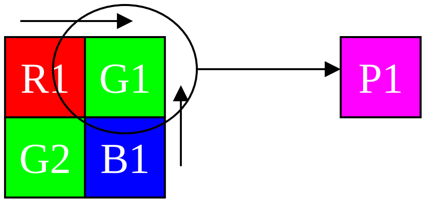
Conclusion

Color Plane Interpolation Methods

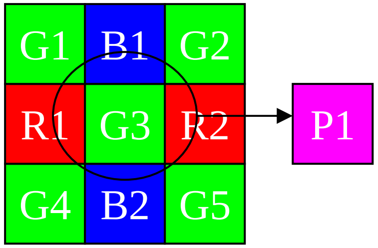
- Pixel Averaging
  - lose image resolution



- Nearest Neighbor
  - Poorest Quality



- Bilinear/Spline
  - Color artifacts at edges

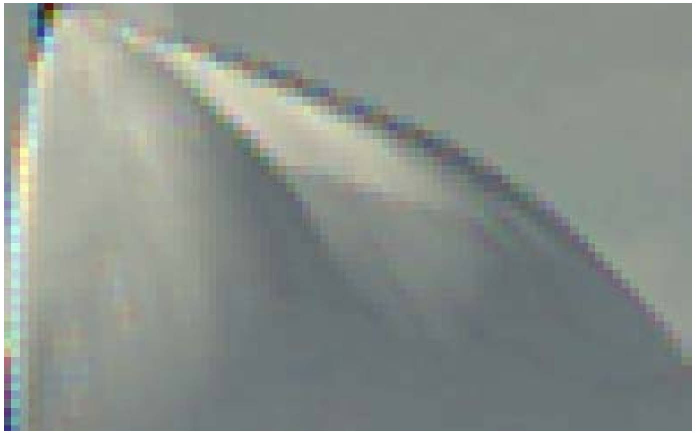


Basics and Challenges

Color Artifacts

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

Original Image

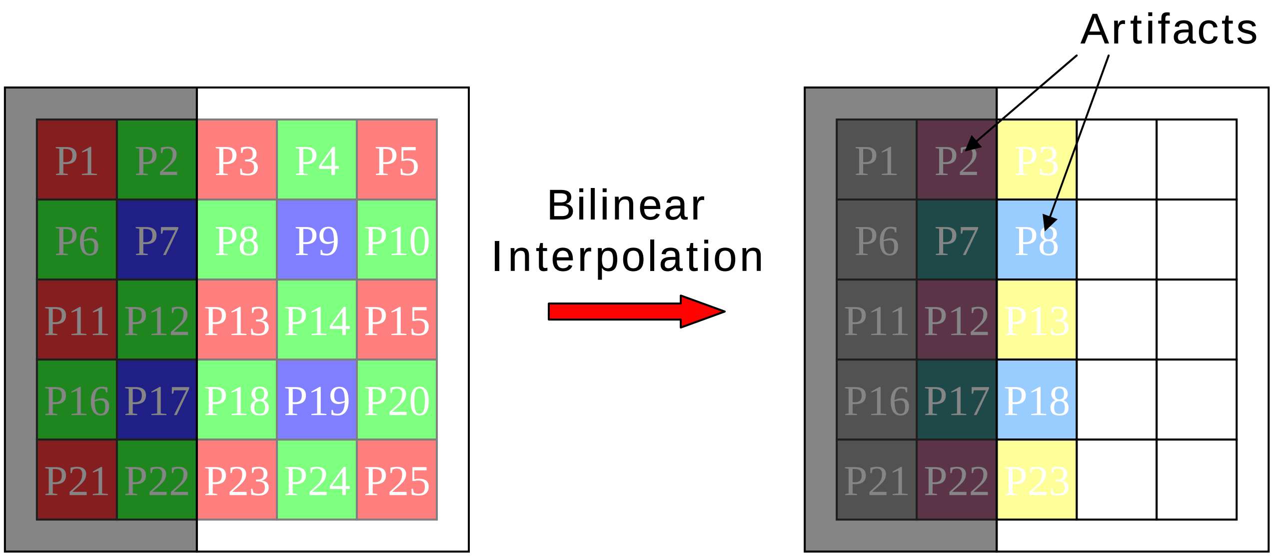


Bilinear Interpolation of Bayer Image

Basics and Challenges

Color Artifacts

- Due to interpolation across edges.



Dark to Light Edge over Bayer Pattern

Resulting Edge after Interpolation

Advanced Methods

Background

Basics

Advanced Methods

Channel Reconstruction

Conclusion

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

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1. GRADIENTS

Using Gradients for Image Reconstruction

- Better estimation of color plane behavior.

P1	P2	P3
P4	P5	P6
P7	P8	P9

Bayer Pattern for Green Centered Pixel

$$Dx(P5) = \frac{P4 - P6}{2} \qquad Dy(P5) = \frac{P2 - P8}{2}$$

$$Dxd(P5) = \frac{P3 - P7}{2\sqrt{2}} \qquad Dyd(P5) = \frac{P1 - P9}{2\sqrt{2}}$$

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

Advanced Methods

1. GRADIENTS
2. GROUPING

Kimmels 'E' Function for Pixel Grouping

- Associates colors of the same object.

P1	P2	P3
P4	P5	P6
P7	P8	P9

Bayer Pattern for Green Centered Pixel

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

$$Ei(P5) = \frac{1}{\sqrt{1 + Di(P5)^2 + Di(Pi)^2}}$$

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

Advanced Methods

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Using Edge Detection (Wide)

- Interpolation is best performed in the same direction as an edge.

P1	P2	P3	P4	P5
P6	P7	P8	P9	P10
P11	P12	P13	P14	P15
P16	P17	P18	P19	P20
P21	P22	P23	P24	P25

Bayer Pattern for Red Centered Pixel

Edge detection of radius 3

$$\Delta H_G(P13) = \left|P12_G - P14_G\right|$$

$$\Delta V_G(P13) = \left|P8_G - P18_G\right|$$

$$\Delta H_R(P13) = \left|P11_R + P15_R - 2 \times P13_R\right|$$

$$\Delta V_R(P13) = \left|P3_R + P23_R - 2 \times P13_R\right|$$

1. GRADIENTS
2. GROUPING
3. EDGE DETECT 3 pxls

Advanced Methods

Background

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Advanced Methods

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Narrow Edge Detection

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

P1	P2	P3	P4	P5
P6	P7	P8	P9	P10
P11	P12	P13	P14	P15
P16	P17	P18	P19	P20
P21	P22	P23	P24	P25

Bayer Pattern for Red Centered Pixel

Edge detection of radius 2

$$\Delta H_{GR}(P13) = \left| P12_G + P14_G - 2P13_R \right|$$

$$\Delta V_{GR}(P13) = \left| P2_G + P8_G - 2P13_R \right|$$

$$\Delta H_{GB}(P13) = \tfrac{1}{2}\left(\left| P7_B + P9_B - 2P8_G \right| + \left| P17_B + P19_B - 2P18_B \right| \right)$$

$$\Delta V_{GB}(P13) = \tfrac{1}{2}\left(\left| P7_B + P17_B - 2P12_G \right| + \left| P9_B + P19_B - 2P14_B \right| \right)$$

1. GRADIENTS
2. GROUPING
3. EDGE DETECT 3 pxls
4. EDGE DETECT 2 pxls

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.

$$C_{GR} = \left| \overline{G}_{5x5} - \overline{R}_{5x5} \right|$$

$$C_{GB} = \left| \overline{G}_{5x5} - \overline{B}_{5x5} \right|$$

P1	P2	P3	P4	P5
P6	P7	P8	P9	P10
P11	P12	P13	P14	P15
P16	P17	P18	P19	P20
P21	P22	P23	P24	P25

Bayer Pattern for Red Centered Pixel

1. GRADIENTS
2. GROUPING
3. EDGE DETECT 3 pxls
4. EDGE DETECT 2 pxls
5. COLOR CORRELATION

Advanced Methods

Background

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Advanced Methods

Channel Reconstruction

Conclusion

Improved Edge Detector

- Now we can complete the edge detector

3 4 5

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

$$\Delta V = \Delta V_R + \Delta V_G + \begin{cases} \Delta V_{GR} & \text{if} \quad C_{GR} \leq C_{GB} \\ \Delta V_{GB} & \text{otherwise} \end{cases}$$

1. GRADIENTS
2. GROUPING
3. EDGE DETECT 3 pxls
4. EDGE DETECT 2 pxls
5. COLOR CORRELATION

6. IMPROVED EDGE DETECTION

Channel Reconstruction

Channel Reconstruction Overview

- For each pixel we now have: $Ei(Pi)$ ΔH ΔV
- 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

Background

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Green Channel Reconstruction

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

P7	P8	P9
P12	P13	P14
P17	P18	P19

Bayer Pattern for Red Centered Pixel

$$P13_G = P13_R + \begin{cases} \dfrac{E_{P12}(P12_G - P12_{R'}) + E_{P14}(P14_G - P14_{R'})}{E_{P12} + E_{P14}} & \text{if} \quad \Delta H > \Delta V \\ \dfrac{E_{P8}(P8_G - P8_{R'}) + E_{P18}(P18_G - P18_{R'})}{E_{P8} + E_{P18}} & \text{if} \quad \Delta H < \Delta V \\ \dfrac{\sum_{i=8,12,14,18} E_{Pi}(Pi_G - Pi_{R'})}{\sum_{i=8,12,14,18} E_{Pi}} & \text{otherwise} \end{cases}$$

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

1. GRADIENTS
2. GROUPING
3. EDGE DETECT 3 pxls
4. EDGE DETECT 2 pxls
5. COLOR CORRELATION

6. IMPROVED EDGE DETECTION

Channel Reconstruction

Background

Basics

Advanced Methods

Channel Reconstruction

Conclusion

Blue and Red Channel Reconstruction

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

P1	P2	P3	P4	P5
P6	P7	P8	P9	P10
P11	P12	P13	P14	P15
P16	P17	P18	P19	P20
P21	P22	P23	P24	P25

Bayer Pattern for Red Centered Pixel

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

Where… $Ki = Pi_B - Pi_G$

Similar approach is taken for completing Red channel.

1. GRADIENTS
2. GROUPING
3. EDGE DETECT 3 pxls
4. EDGE DETECT 2 pxls
5. COLOR CORRELATION

6. IMPROVED EDGE DETECTION

Conclusion

Conclusion

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

Thank You

References

[1] D. Darian Muresan, S. Luke, and T. W. Parks, “Reconstruction of Color Images From CCD Arrays,” *Cornell University, Ithaca NY. 1485,*

[2] R. Kimmel, “Demosaicing: Image Reconstruction from Color CCD Samples” *IEEE Transl. J. Image Processing*, vol. 8, Sept. 1999.

[3] Xiaomeng Wang, Weisi Lin, Ping Xue, “Demosaicing with Improved Edge Direction Detection” *IEEE Transl. J. Image Processing*, 2005.