Removal of Specular Reflection with Spectral Deconvolution

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Project Overview

- Design a low cost endoscopic adapter
  - Needed for third world use where costs are major issues
  - Useful in emergency situations
  - Allows for rapid image sharing when doctors are not on site

- Create a system for Android devices
  - Current solutions only work with iPhones (Endoscope-I)
  - Improve the Image Quality
    - Remove specular reflection that occurs frequently in Endoscope-I (Maximum Deliverable)
Selected Papers

  – Cited ~16 times

  – Cited ~64 times
  – Originally developed for error concealment in video communication
  – Frequency selective signal extrapolation was used in Stehle (2006)
Stehle (2006) Introduction

• Specular reflection: light source of the endoscope, facing into the same direction as the camera
  – Due to the moistness of a mucosa
  – Clinicians remove adjust of endoscope camera to lessen its effect

• Original goal: to remove specular reflection in PillCam (wireless endoscope)
  – PillCam’s camera direction can’t be controlled

• Idea:
  – Segment the reflective region (High Luminance)
  – Correct the region by interpolation

Courtesy of http://drawingin.blogspot.com/2012/05/pillcam.html
Stehle (2006) Method Overview

RGB Camera Image → RGB to YUV Conversion → Segmentation by Y (Luminance) → Enlargement Segmented Image (Erosion) → Corrected Image → Defect Interpolation → Correction

Segmentation
Stehle (2006) Method 1.1: RGB to YUV Conversion

- Image can be converted to YUV space
- Luminance information is obtained per pixel (Y channel)

\[
\begin{bmatrix}
Y \\
U \\
V
\end{bmatrix}
= \begin{bmatrix}
0.299 & 0.587 & 0.114 \\
-0.147 & -0.289 & 0.436 \\
0.615 & -0.515 & -0.100
\end{bmatrix}
\begin{bmatrix}
R \\
G \\
B
\end{bmatrix}
\]
Stehle (2006) Method 1.2: Segmentation by Y

- Small peak on the right corresponds to pixels that contain specular reflections
- Cutoff luminance can be determined from histogram
- Segmented as 1 if it is normal pixel, 0 if it is defective pixel with specular reflection

Adapted from Figure 1 of Stehle (2006)

- Segmented region (0: defective pixel) is enlarged
  - We have black segment on white background
  - For smoother edge
- 9x9 circular structure was used

[Diagram of image processing with 9x9 circular structure used for erosion]

- Iterative method to estimate DFT
  - Theoretical work done in Kaup et al. (2005).

Adapted from Stehle (2006)
Section 2.2 Spectral Deconvolution

- Iterative method to estimate DFT

\[ \hat{F}^{(i)}(k) \]: estimated image \( F(k) \), computed by estimated coefficients \( G(s) \), \( G^{(i-1)}(N-S) \)

- \( G^{(i)}(k) \): error after deconvolution with estimated coefficients

\[
G^{(i)}(k) = G(k) - \frac{1}{N} \cdot \hat{F}(k) \ast W(k) \\
= G(k) - \frac{1}{N} \left( \hat{F}(s) \cdot W(k-s) + \hat{F}^*(s) \cdot W(k+s) \right)
\]

- Note that \( F(k) = F^*(N-k) \)

Adapted from Stehle (2006)
Section 2.2 Spectral Deconvolution

- Iterative method to estimate DFT
  - The goal of iterative method is to minimize the error, \( G^{(i)}(k) \), or to maximize the energy reduction

\[
E_g = \sum_{n=0}^{N-1} (g^{(1)}(n))^2 = \frac{1}{N} \sum_{k=0}^{N-1} |G^{(1)}(k)|^2
\]

\[
= \frac{1}{N} \cdot E_G \cdot \text{(Parseval’s thm)}
\]

- \( \Delta E \): energy reduction

\[
\Delta E(\hat{F}(s^{(i)})) = \frac{1}{N^2} \sum_{k=0}^{N-1} \left| \hat{F}(s^{(i)})W(k-s^{(i)}) + \hat{F}^*(s^{(i)})W(k+s^{(i)}) \right|^2
\]

- \( G^{(i-1)}(s), G^{(i-1)}(N-s) \) or \( G^{*(i-1)}(s) \): a pair of spectral coefficients

\[
G^{(i-1)}(s^{(i)}) = \frac{1}{N} \left( \hat{F}(s^{(i)})W(0) + \hat{F}^*(s^{(i)})W(2s^{(i)}) \right)
\]

\[
G^{*(i-1)}(s^{(i)}) = \frac{1}{N} \left( \hat{F}^*(s^{(i)})W(0) + \hat{F}(s^{(i)})W^*(2s^{(i)}) \right)
\]

- Iterative method to estimate DFT

\[
\hat{F}(s^{(i)}) = \frac{G^{(i-1)}(s^{(i)})W(0) - (G^{(i-1)}(s^{(i)}))^* W(2s^{(i)})}{N} \frac{1}{|W(0)|^2 - |W(2s^{(i)})|^2}.
\]

Adapted from Stehle (2006)
Section 2.2 Spectral Deconvolution

- Iterative method to estimate DFT

\[ G^{(i)}(k) = G^{(i-1)}(k) - \frac{1}{N} \cdot \hat{F}^{(i-1)}(k) \ast W^{(i-1)}(k) \]

\[ = G^{(i-1)}(k) - \frac{1}{N} \left( \hat{F}^{(i-1)}(k) \cdot W^{(i-1)}(k - s) + \hat{F}^{* (i-1)}(k) \cdot W^{(i-1)}(k + s) \right) \]

Adapted from Stehle (2006)
Section 2.2 Spectral Deconvolution
Stehle (2006) Results

- **Description:**
  - Top: Endoscopic image of colon
  - Bottom: Endoscopic image of esophagus
  - Left: Original image
  - Right: Processed image

- **Notable qualitative changes**
  - Specular reflection removed
  - Some detailed information lost
  - Artifacts were added

Adapted from Figure 3 and Figure 4 of Stehle (2006)
Implication and Future Work

• Criticism:
  – Experiment not performed on video
  – Lack of numerical, quantitative evaluation
  – Lack of feedback from clinicians
  – Running time

• Implication
  – Iterative steps not suitable for real-time image processing
  – Lose of fine details, addition of artifacts not suitable for medical application

• Possible work:
Questions?
Kaup et al. (2005) Results

- Concealment of block losses using the frequency selective extrapolation technique

Adapted from Figure 5 of Kaup et al. (2005)