Removal of Specular Reflection with Spectral Deconvolution

Group #7 Project Seminar Presentation
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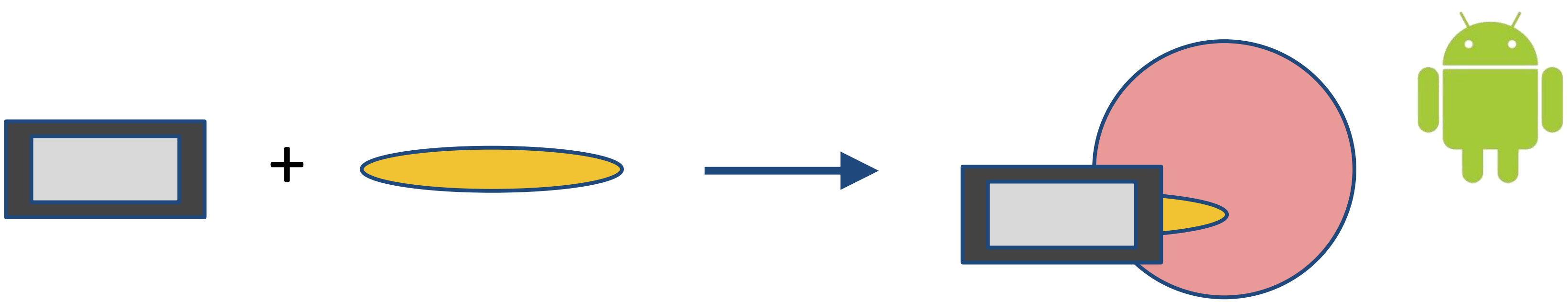
Project Overview

- 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)

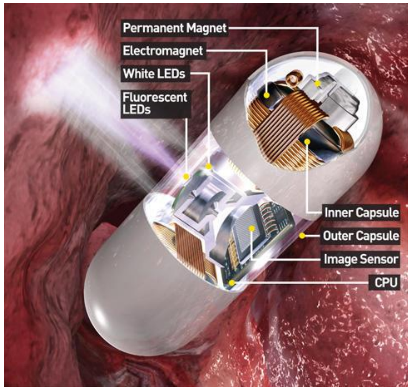


Selected Papers

- Stehle, Thomas. **"Removal of specular reflections in endoscopic images."** *Acta Polytechnica* 46.4 (2006).
  - Cited ~16 times
- Kaup, André, Katrin Meisinger, and Til Aach. **"Frequency selective signal extrapolation with applications to error concealment in image communication."** *AEU-International Journal of Electronics and Communications* 59.3 (2005): 147-156.
  - Cited ~64 times
  - Originally developed for error concealment in video communication
  - Frequency selective signal extrapolation was used in Stehle (2006)

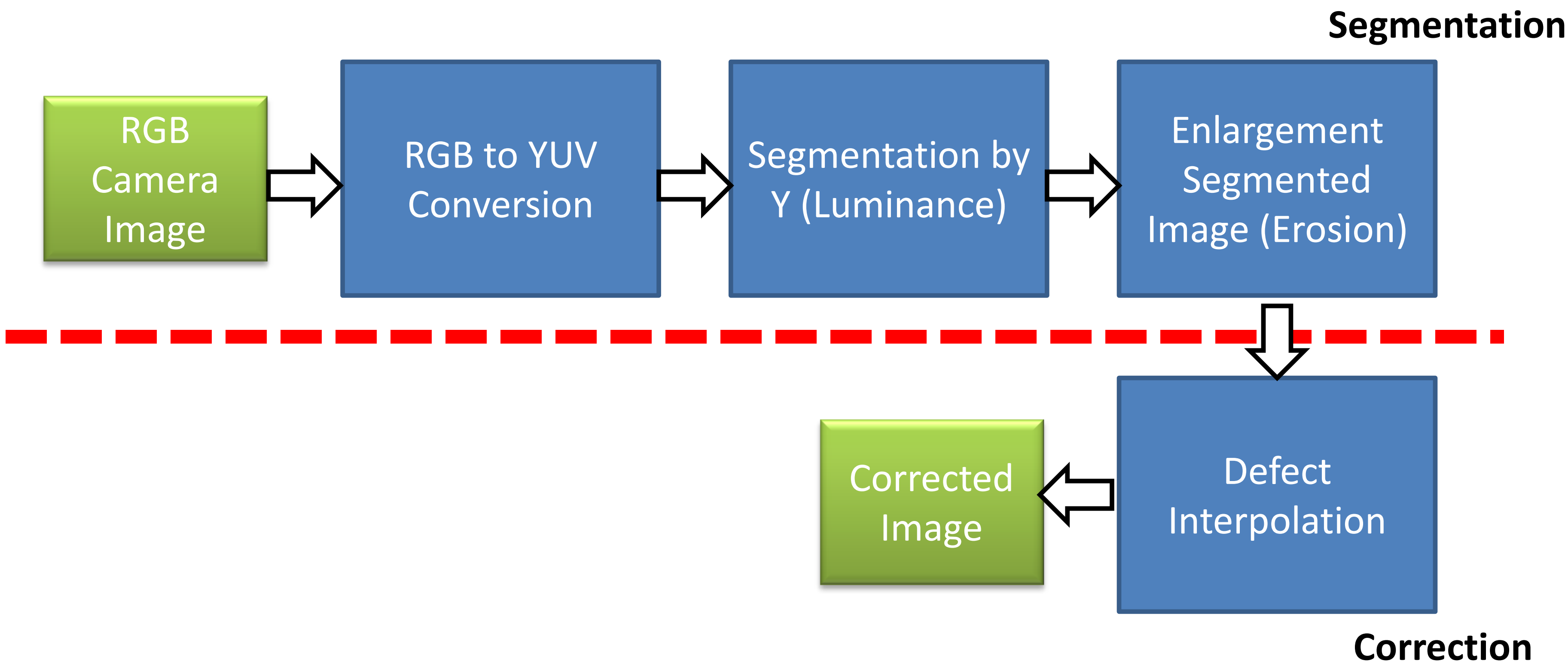
Stehle (2006) Introduction

- 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



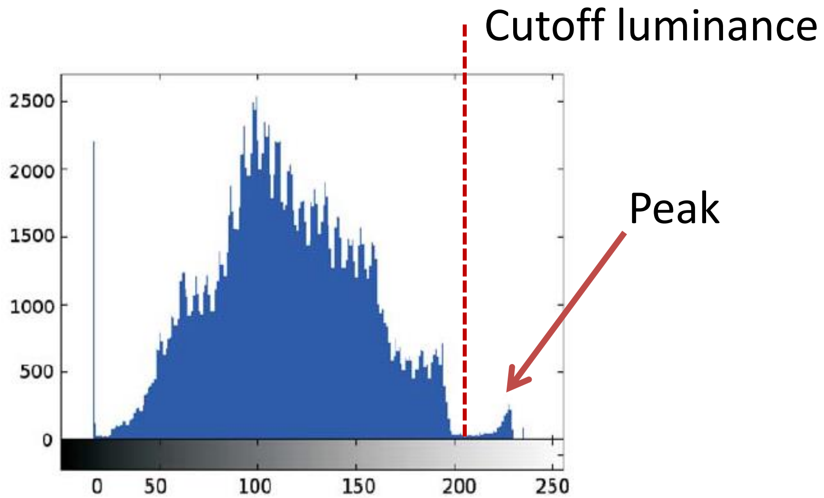
Stehle (2006) Method 1.1: RGB to YUV Conversion

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

$$\begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.147 & -0.289 & 0.436 \\ 0.615 & -0.515 & -0.100 \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

Stehle (2006) Method 1.2: Segmentation by Y

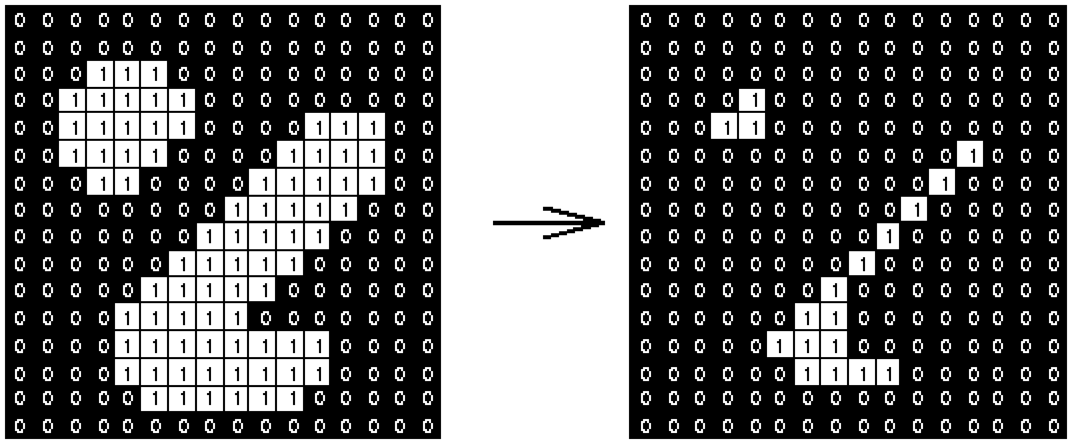
- Small peak on the right corresponds to pixels that contain specular reflections
- Cutoff luminance can be determined from histogram
- Segmented as 1 if it is normal pixel, 0 if it is defective pixel with specular reflection



Adapted from Figure 1 of Stehle (2006)

Stehle (2006) Method 1.3: Erosion

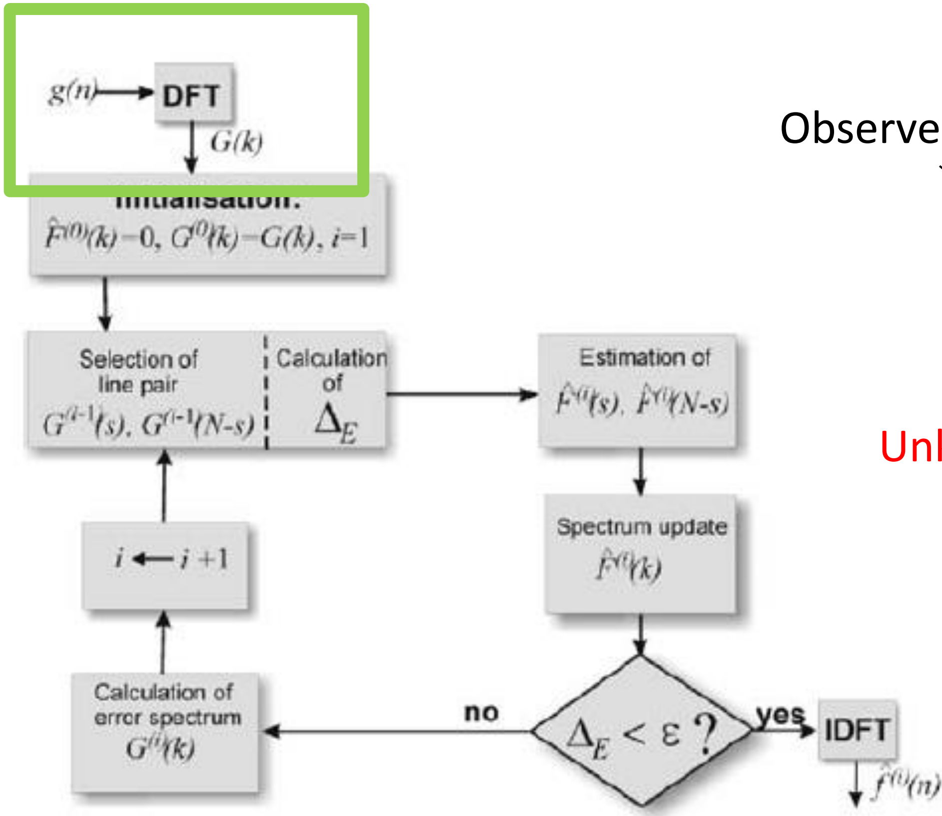
- Segmented region (0: defective pixel) is enlarged
  - We have black segment on white background
  - For smoother edge
- 9x9 circular structure was used



Courtesy of
https://www.cs.auckland.ac.nz/courses/compsci773s1c
/lectures/ImageProcessing-html/topic4.htm

Stehle (2006) Method 2: Spectral Deconvolution Overview

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



Undisturbed image (Unknown)

Observed Image

$$g(n) = f(n) \cdot w(n)$$

Binary window

DFT

Unknown

$$w(n) = \begin{cases} 1 \ if\ normal\ pixel \\ 0 \ if\ reflective\ pixel \end{cases}$$

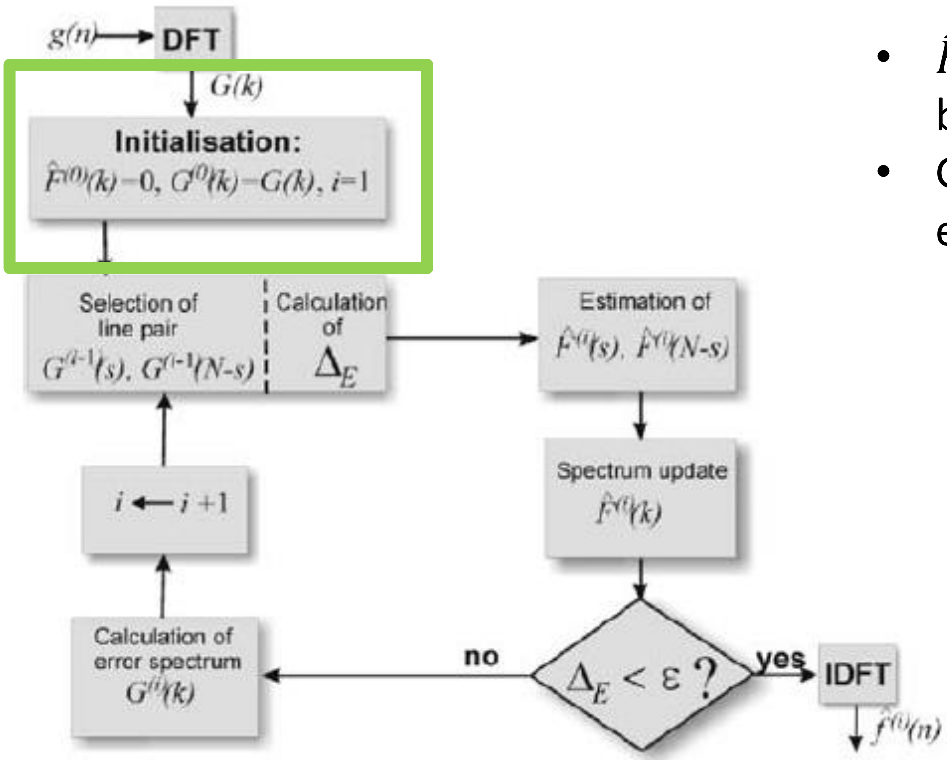
$$G(k) = \frac{1}{N} F(k) * W(k)$$

$$= \frac{1}{N} \sum_{l=0}^{N-1} F(l) \cdot W(k-l)$$

Adapted from Stehle (2006)
Section 2.2 Spectral Deconvolution

Stehle (2006) Method 2.1: Initialization

- 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

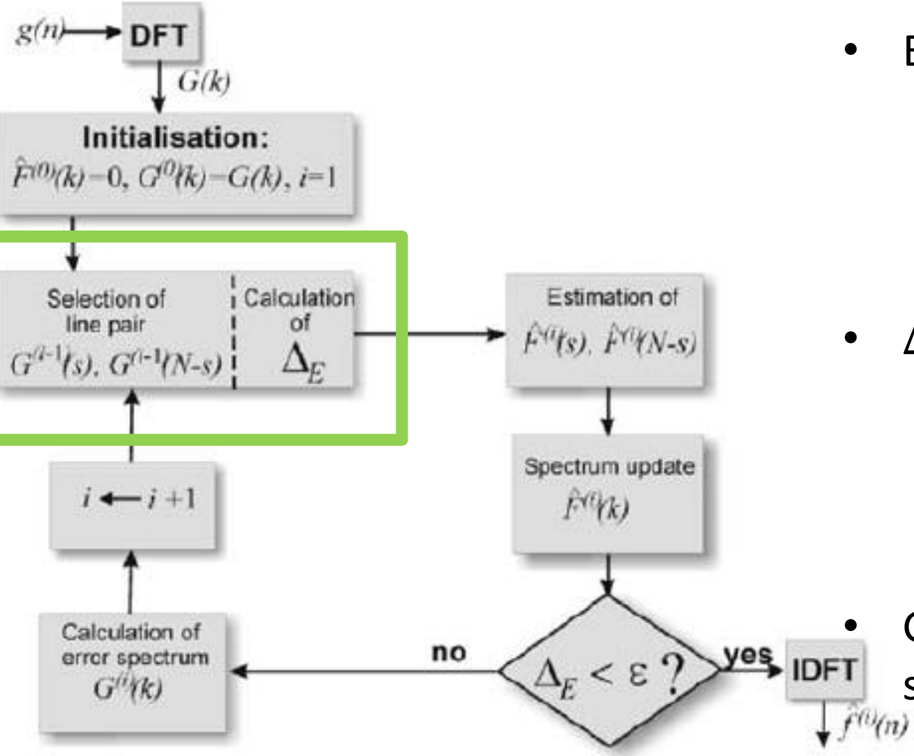
$$G^{(1)}(k) = G(k) - \frac{1}{N} \cdot \hat{F}(k) * W(k)$$
$$= G(k) - \frac{1}{N}\left(\hat{F}(s) \cdot W(k-s) + \hat{F}^{*}(s) \cdot W(k+s)\right)$$

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

Adapted from Stehle (2006)
Section 2.2 Spectral Deconvolution

Stehle (2006) Method 2.2: Energy Reduction

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



Adapted from Stehle (2006)
Section 2.2 Spectral Deconvolution

- E_g: Energy of $G^{(i)}(n)$

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

$$= \frac{1}{N}\cdot E_G \cdot \text{ (Parseval's thm)}$$

- Δ_E: energy reduction

$$\Delta_E\left(\hat{F}(s^{(i)})\right) =$$

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

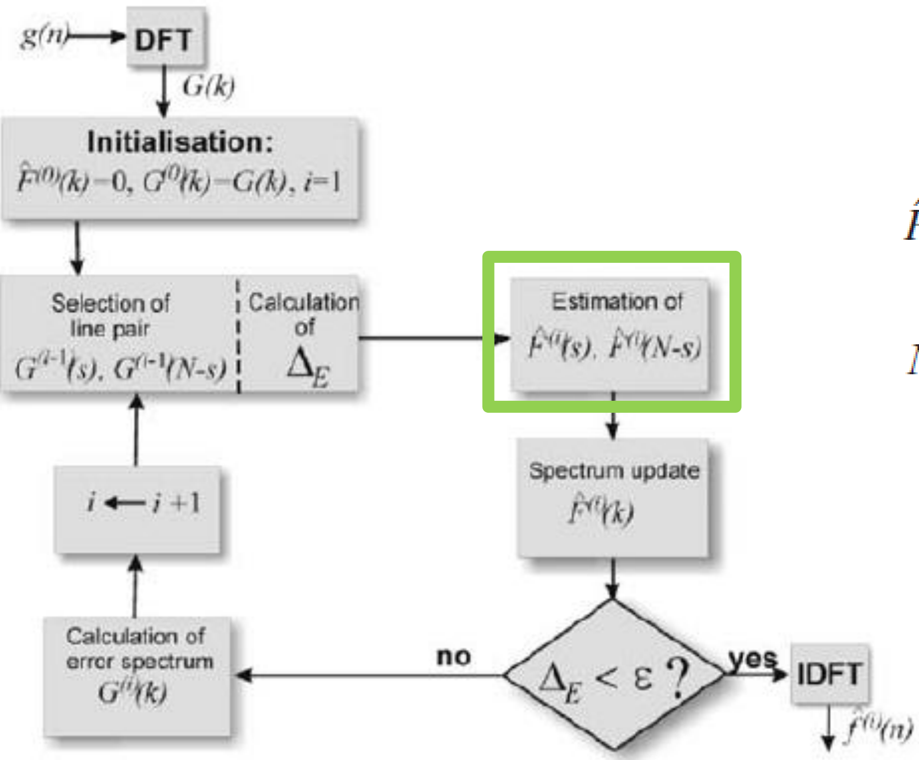
- $G^{(i-1)}(s)$, $G^{(i-1)}(N-s)$ or $G^{*(i-1)}(s)$: a pair of spectral coefficients

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

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

Stehle (2006) Method 2.3: Estimation of Spectral Coefficient

- Iterative method to estimate DFT

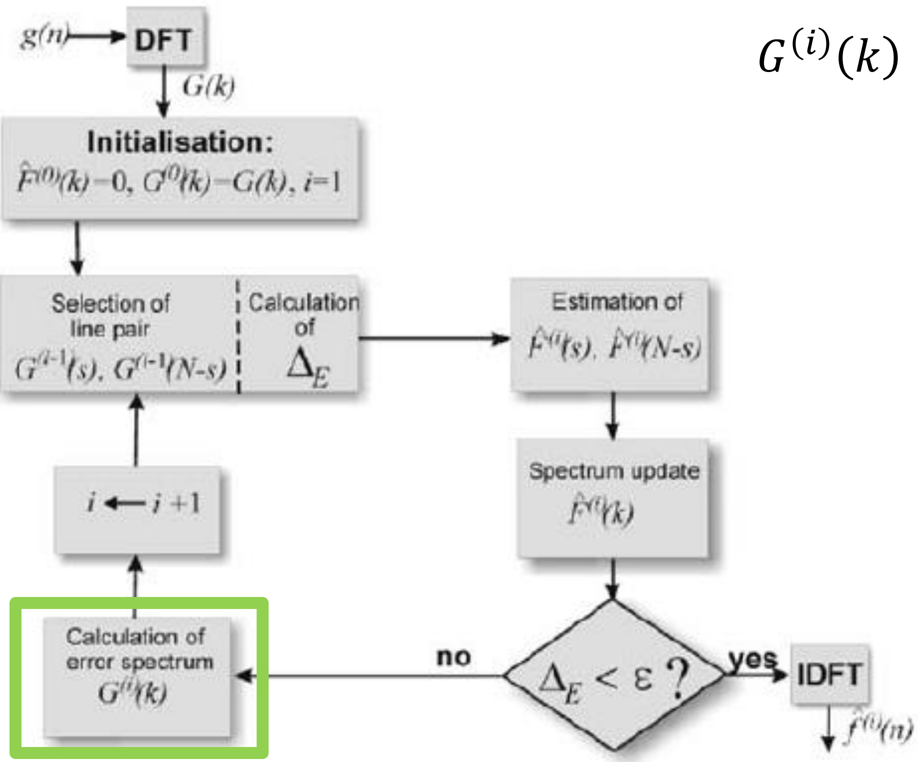


$$\hat{F}(s^{(i)}) = N \frac{G^{(i-1)}(s^{(i)})W(0) - \left(G^{(i-1)}(s^{(i)})\right)^{*} W(2s^{(i)})}{\left|W(0)\right|^{2} - \left|W(2s^{(i)})\right|^{2}}.$$

Adapted from Stehle (2006)
Section 2.2 Spectral Deconvolution

Stehle (2006) Method 2.4: Calculation of Error Spectrum

- Iterative method to estimate DFT

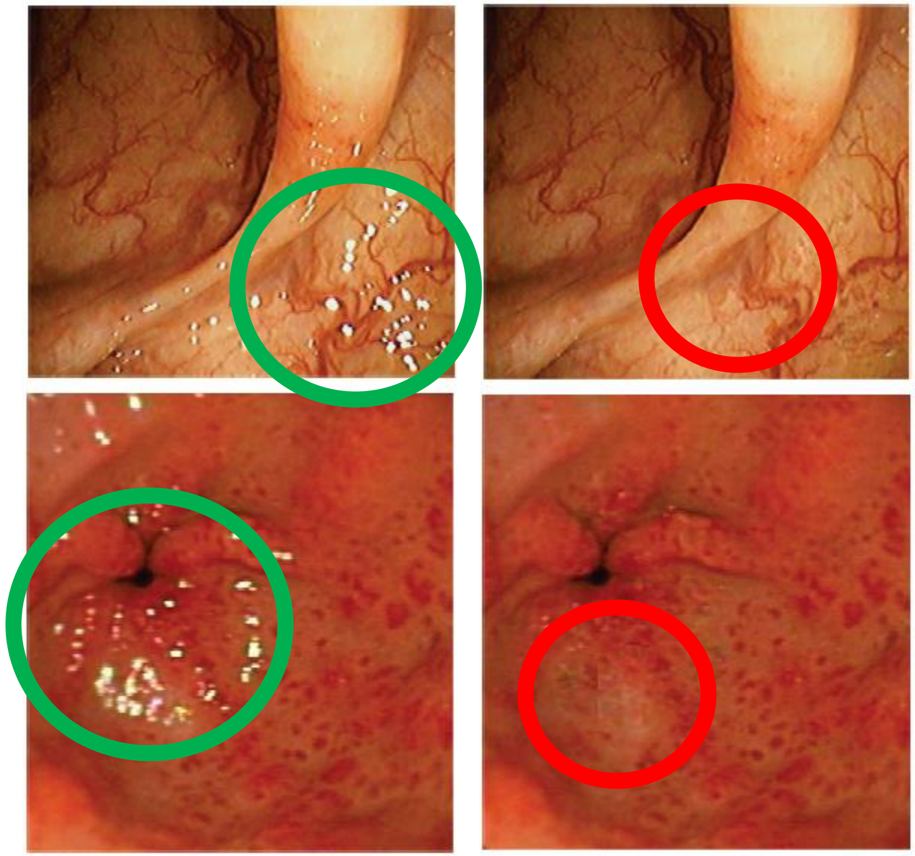


$$G^{(i)}(k) = G^{(i-1)}(k) - \frac{1}{N} \cdot \hat{F}^{(i-1)}(k) * W^{(i-1)}(k)$$
$$= G^{(i-1)}(k) - \frac{1}{N}\left(\hat{F}^{(i-1)}(k) \cdot W^{(i-1)}(k-s) + \hat{F}^{*(i-1)}(k) \cdot W^{(i-1)}(k+s)\right)$$

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:
  - Nayar, Shree K., Xi-Sheng Fang, and Terrance Boult. **"Separation of reflection components using color and polarization."** *International Journal of Computer Vision* 21.3 (1997): 163-186.
  - Oh, JungHwan, et al. **"Informative frame classification for endoscopy video."** *Medical Image Analysis* 11.2 (2007): 110-127.

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)