

Removal of Specular Reflection with Spectral Deconvolution

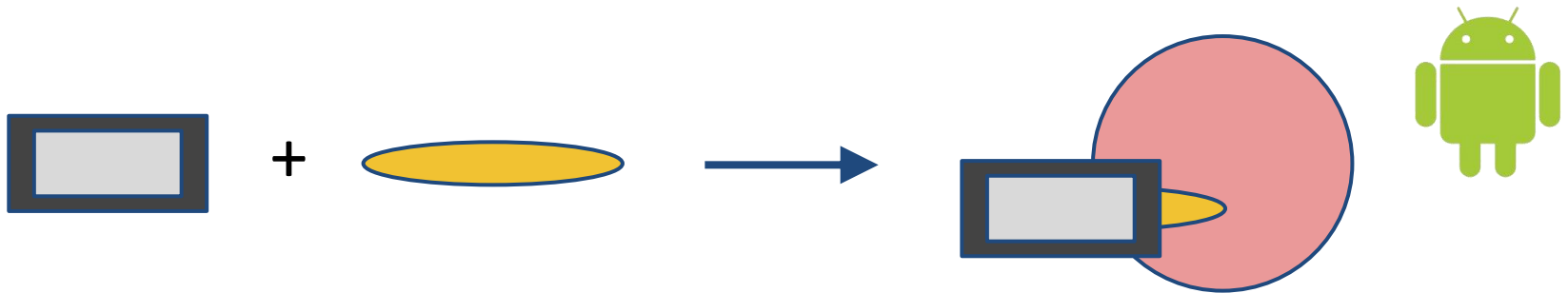
Group #7 Project Seminar Presentation
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Project Overview

- 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)

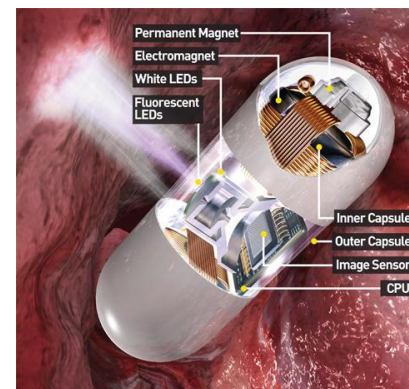


Selected Papers

- 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)

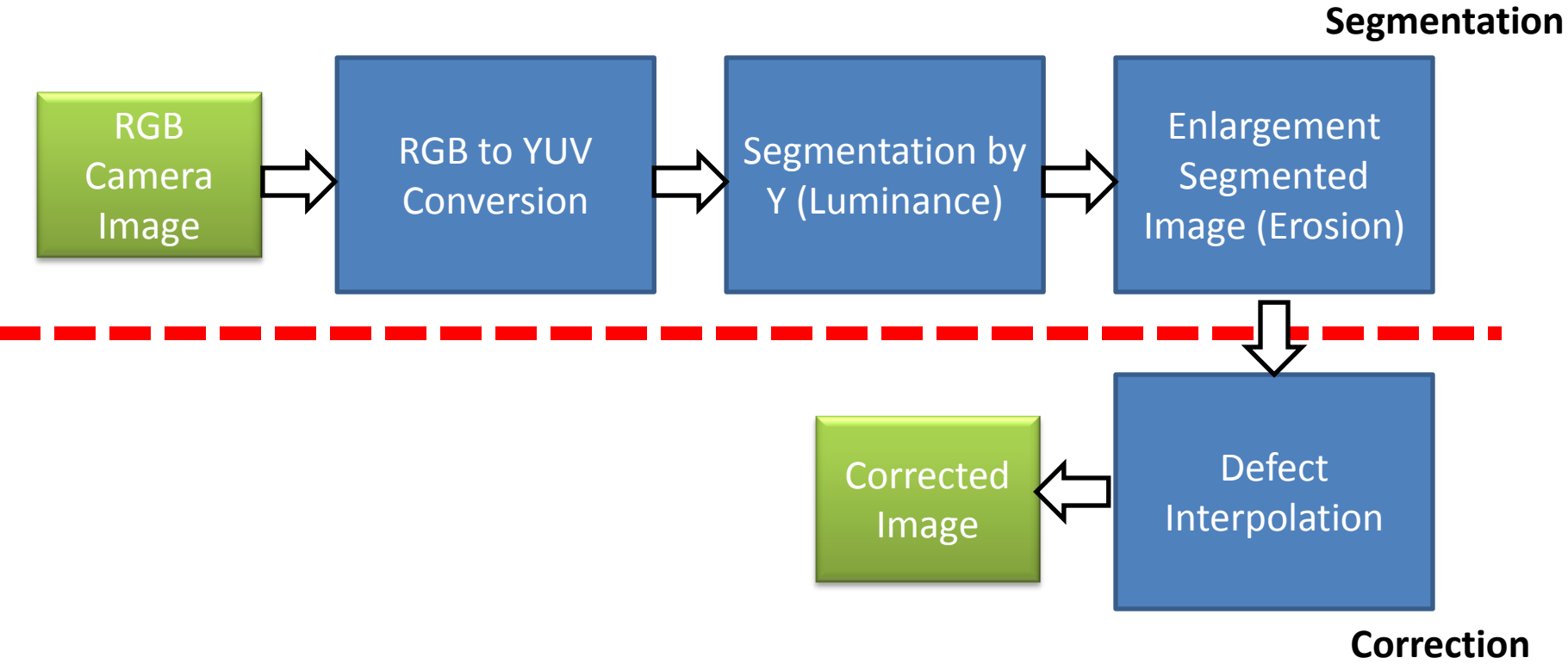
Stehle (2006) Introduction

- 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



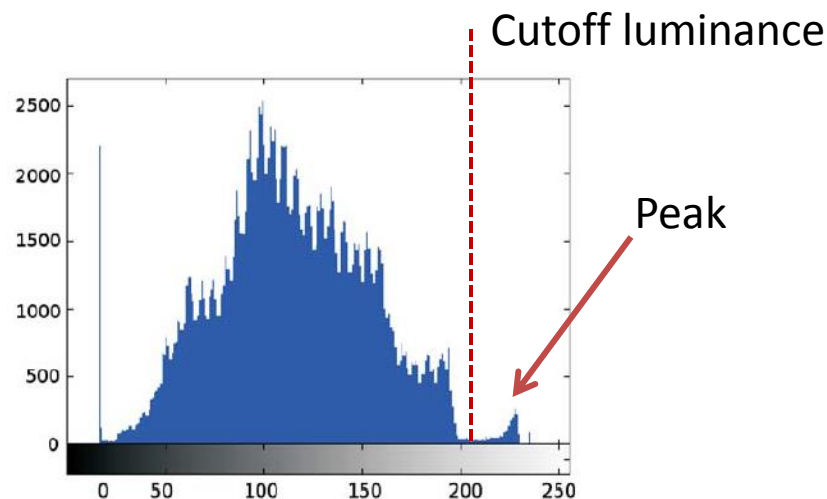
Stehle (2006) Method 1.1: RGB to YUV Conversion

- 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

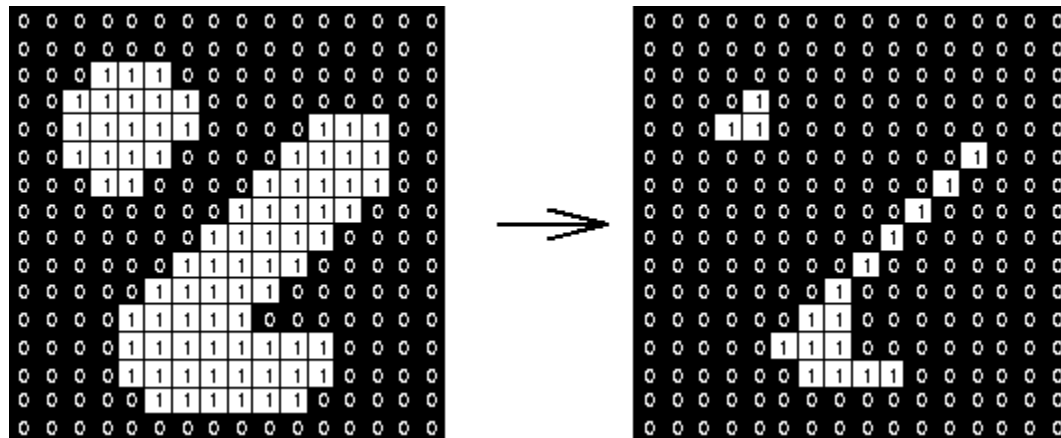
- Small peak on the right corresponds to pixels that contain specular reflections
- Cutoff luminance can be determined from histogram
- Segmented as 1 if it is normal pixel, 0 if it is defective pixel with specular reflection



Adapted from Figure 1 of Stehle (2006)

Stehle (2006) Method 1.3: Erosion

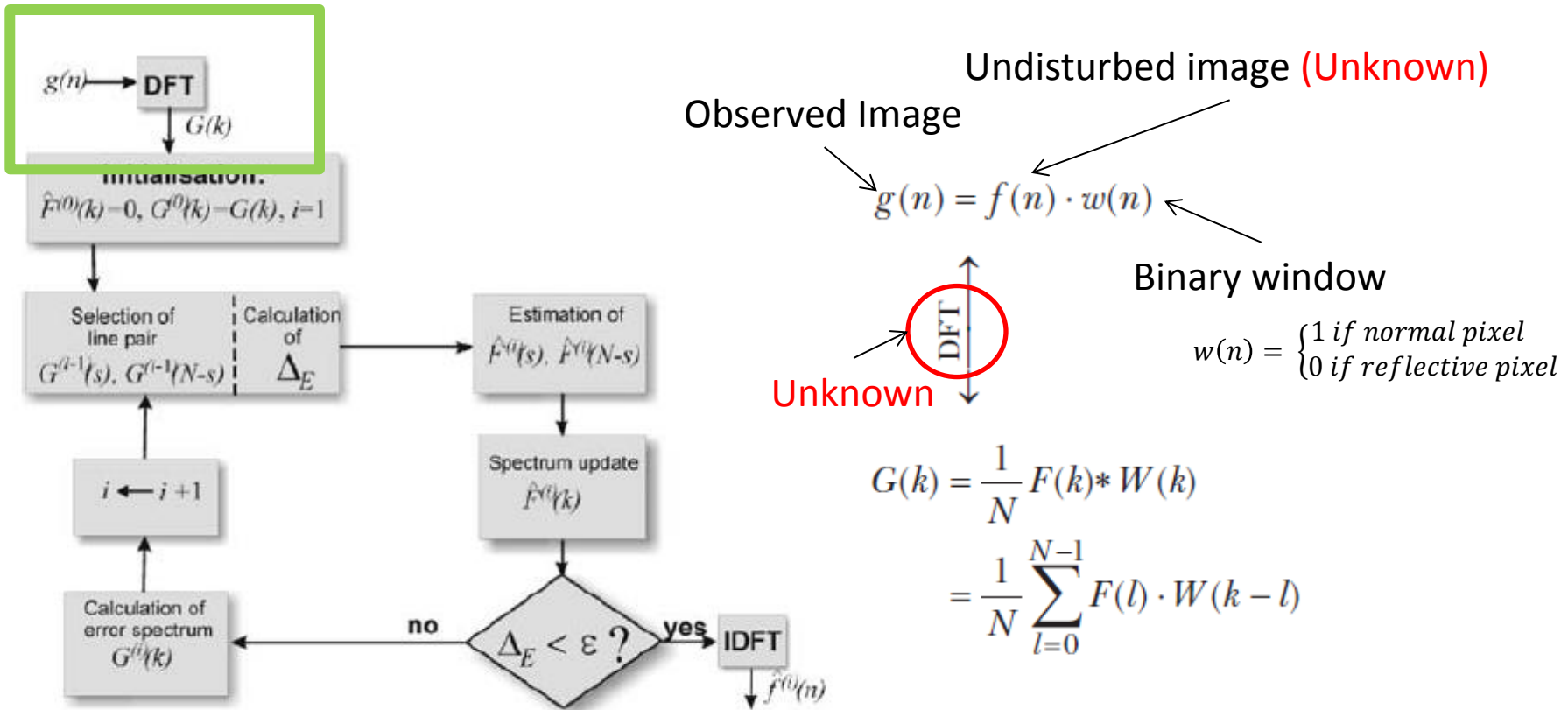
- Segmented region (0: defective pixel) is enlarged
 - We have black segment on white background
 - For smoother edge
- 9x9 circular structure was used



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

Stehle (2006) Method 2: Spectral Deconvolution Overview

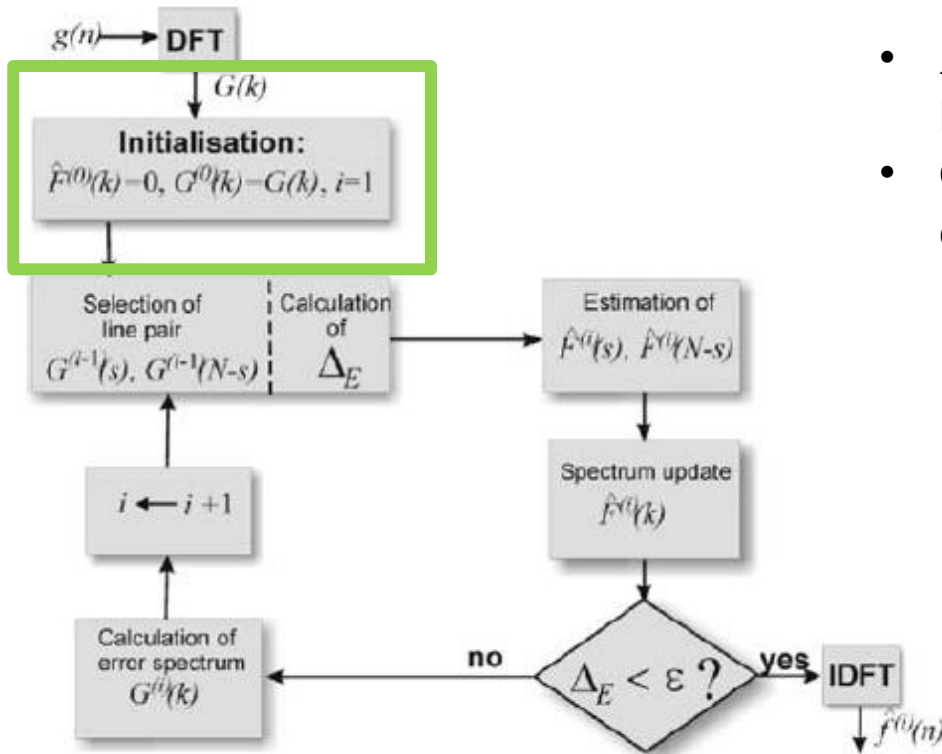
- Iterative method to estimate DFT
 - Theoretical work done in Kaup et al. (2005).



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

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

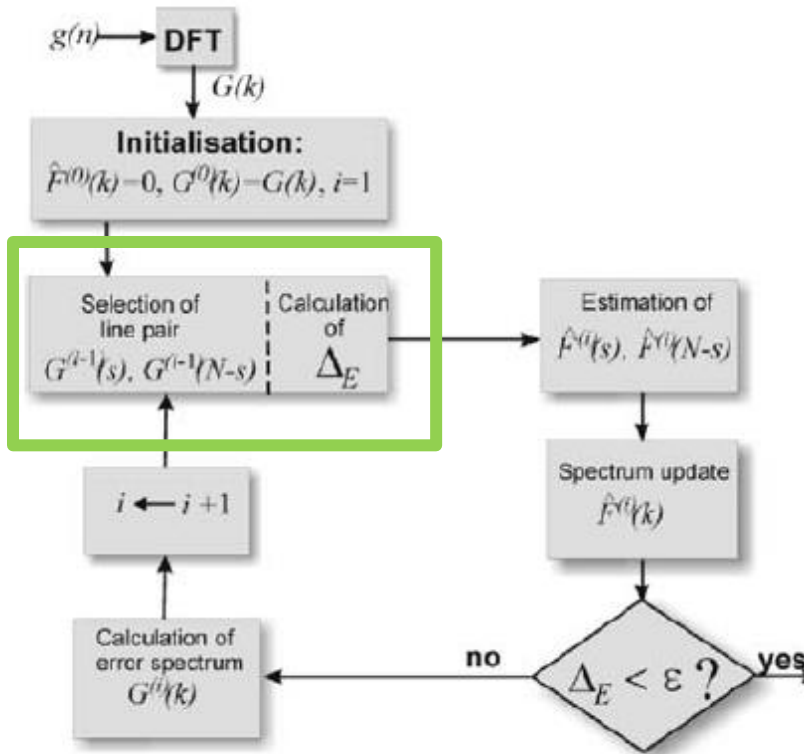
$$= G(k) - \frac{1}{N} (\hat{F}(s) \cdot W(k-s) + \hat{F}^*(s) \cdot W(k+s))$$

- 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



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

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

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

- Δ_E : energy reduction

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

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

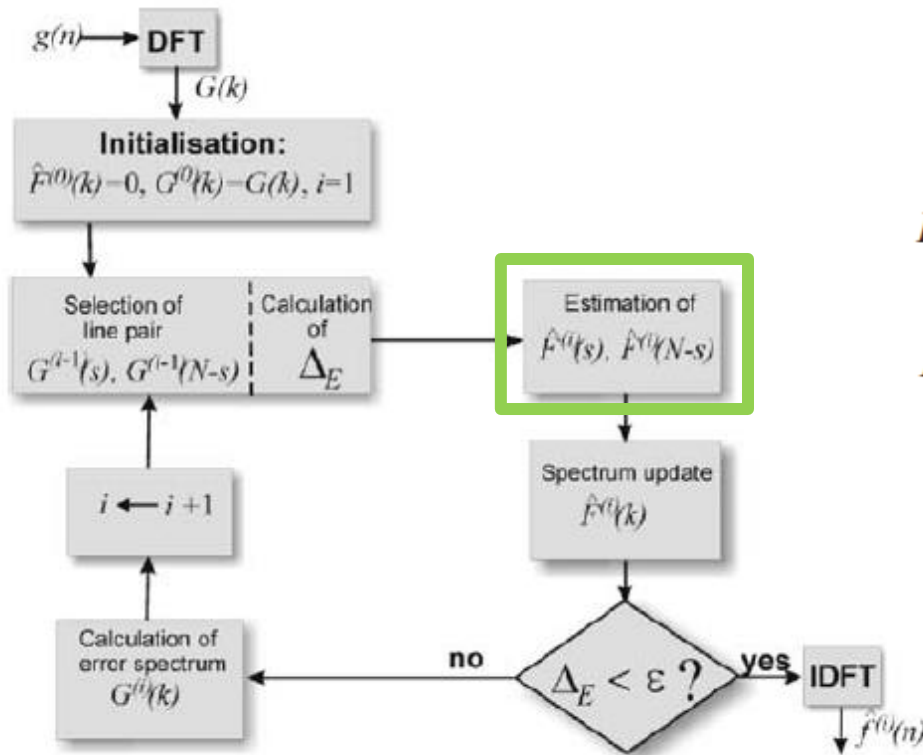
$$G^{(i-1)}(s^{(i)}) = \frac{1}{N} (\hat{F}(s^{(i)})W(0) + \hat{F}^*(s^{(i)})W(2s^{(i)}))$$

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

Adapted from Stehle (2006)
Section 2.2 Spectral Deconvolution

Stehle (2006) Method 2.3: Estimation of Spectral Coefficient

- Iterative method to estimate DFT

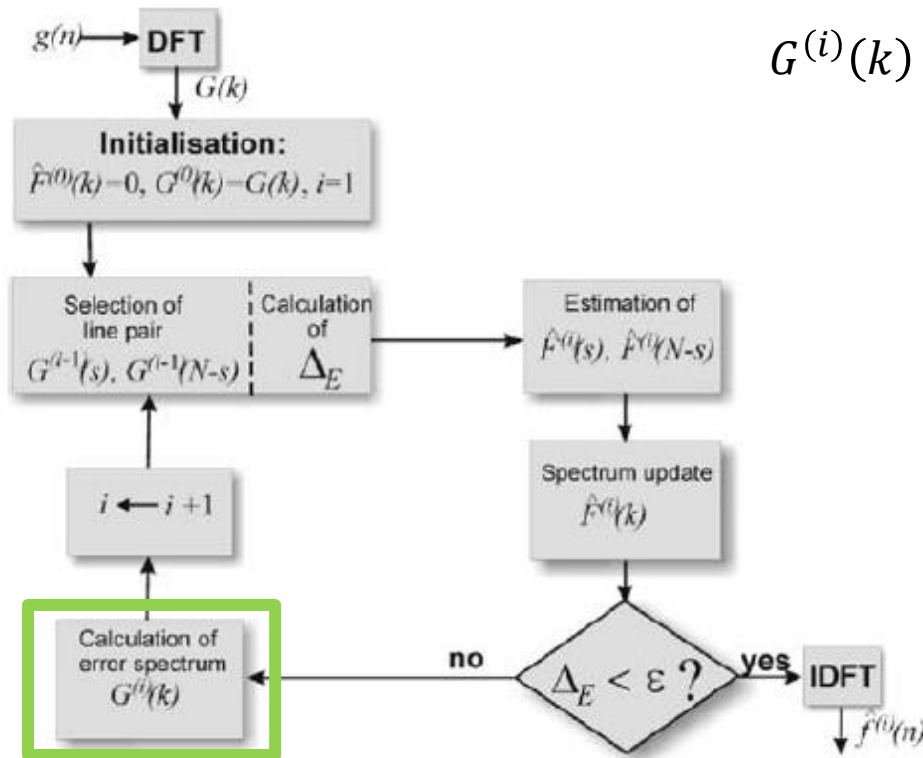


$$\hat{F}(s^{(i)}) = \frac{G^{(i-1)}(s^{(i)})W(0) - \left(G^{(i-1)}(s^{(i)})\right)^* W(2s^{(i)})}{N \left(|W(0)|^2 - |W(2s^{(i)})|^2 \right)}$$

Adapted from Stehle (2006)
Section 2.2 Spectral Deconvolution

Stehle (2006) Method 2.4: Calculation of Error Spectrum

- Iterative method to estimate DFT

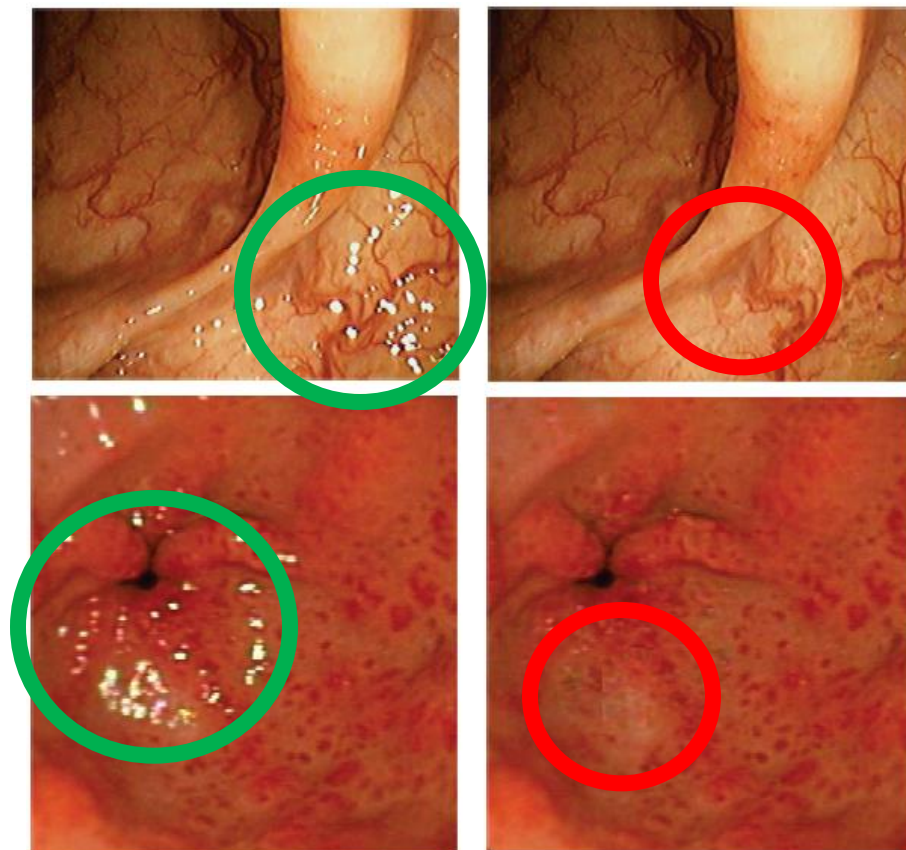


$$\begin{aligned}
 G^{(i)}(k) &= G^{(i-1)}(k) - \frac{1}{N} \cdot \hat{F}^{(i-1)}(k) * W^{(i-1)}(k) \\
 &= G^{(i-1)}(k) \\
 &\quad - \frac{1}{N} (\hat{F}^{(i-1)}(k) \cdot W^{(i-1)}(k - s) \\
 &\quad + \hat{F}^{*(i-1)}(k) \cdot W^{(i-1)}(k + s))
 \end{aligned}$$

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)