Case Study: Scalable Edge Enhancement

Introduction

- Edge enhancement is a post processing for displaying radiologic images on the monitor to achieve as good visual quality as the film printing does.
- Edges can be enhanced by applying a high-pass filter, which is implemented by applying an "edge kernel operator". The greater degree the edge enhanced, the more the noise introduced.
- Theoretically, a "large-size kernel" should be used in order to reduce the noise. However, it is very time-consuming in computation, which is unbearable for doctors or technitians in real work.
- To make the degree of edge enhancement adjustable, different kernels must be used.
- There is a trade-off between the processing time and the visualization quality.

Advantages of Scalable Edge Enhancement (SEE)

- High speed:
  - Only one small-size kernel is applied once; only the sub-sampled image is processed.
- High perceptual quality:
  - Increasing more meaningful edges while suppressing the noises.
- Progressive instant display:
  - Enhanced images at various degrees can be displayed using different scales with a "fixed-size" edge image.
  - Adjustable scale factors provide more flexibility for doctors.
Traditional Edge Enhancement (EE)

- **Principles:**
  - Original image (I) (e.g., 3K x 3K)
  - Enhanced image (E) (e.g., 3K x 3K)

- **Implementation:**
  - Convolution

- **Formulation:**
  \[ E = I * K \]

- **Principle:**
  - Applying the edge enhancement in a shrank image domain
  - Extracting the edge information
  - Scaling the edge information, and adding it onto the original image

- **Formulation:**
  \[ E = I + S \]

- **Diagram of SEE**
  - Sub-sampling
  - Edge Enhancing
  - Interpolation
  - (Edge Scaling)
  - Scale Factor

Scalable Enhancement and Optimization
**Instance of SEE**

- Kernel

K = 

- Modified Kernel

K’ = 

Note: If K’ is used, the edge can be obtained directly from the convolution operation, so that the “subtraction” in the diagram of SEE can be avoided.

- Image Size: 3k x 3k
- Sub-sample Image Size: 1k x 1k
- Speed: less than 1 second

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**Discussion:**

- Based on the requirement of doctors, investigate the relation between the edge scale level and the specific radiological image.
- Investigate adaptive edge enhancement algorithm for different regions of interest.
- Hardware realization.

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**Case Study:**

**Auto Image Optimization**
Introduction

- Auto Image Optimization is a technique used to automatically optimize the contrast range of the image in real time.
- In the past, the doctor or technician optimized the contrast range of the images by adjusting the window and level settings for each image individually.

Benefits of Auto Image Optimization

- Unsubtracted Spot and Tomo image are optimized automatically in real time prior to display on the monitor.
- The images displayed during the exam do not need further contrast processing prior to hardcopy or transfer to a review station.
- Increase patient workflow due to less post processing.
- Increase dynamic range: iris calibration is no longer adjusted for optimum contrast presentation. Now it can be calibrated for maximum dynamic range.

Contrast Transfer Function

- Above is a block diagram of the contrast transfer functions of various components in the GoldOne Imaging chain.
- Each of these blocks will be discussed in more detail.
The x-ray tube emits x-ray photons from a small focal spot on a rotating anode. These x-ray photons are collimated to eliminate unnecessary exposure to the patient and to provide a uniform x-ray image impinging on the x-ray detector.

When a patient is placed between the x-ray tube and the x-ray detector some of the x-ray photons are absorbed by the various densities of the patient. The resulting x-ray image impinging on the x-ray detector can be viewed as a shadowgram.

The absorption of x-ray photons through various densities of the patient is non linear. The absorption characteristics can be best described as logarithmic.

Depending on the energy of the x-ray photons impinging on the x-ray detector a large number are absorbed in the scintillator resulting in a conversion from x-ray photons to visible light photons.

These visible light photons are then sensed by a detector (e.g., silicon for flat panel, photo cathode for Image Intensifiers) that generates an electrical signal proportional to the quantity of visible light photons detected.

After x-ray detection by the scintillator and photo-cathode the electrons are accelerated towards a small phosphor screen to display an image.

The x-ray image on the phosphor screen is then projected onto the CCD camera sensor (through the use of relay lens) where the light photons are once again converted back to an electrical signal.

The contrast transfer function of the CCD sensor is relatively linear throughout the usable dynamic range of the sensor. Near full well capacity the CCD sensor becomes very nonlinear.
Acquisition LUTs

- The Acquisition Lookup tables maximizes the contrast range of the acquired image in preparation for image processing, archival and display.
- In the GoldOne product the Acquire Lookup table converts 12-bit data to 10-bit output data. It is extremely important to optimize the dynamic range in the conversion to reduce quantization error resulting from further processing.

Image Statistics

- Image Statistics are gathered on 10 bit data at the output of the Acquire lookup table.
- The following statistics are accumulated (statistics are calculated on 8 pixel average to reduce noise).
- Minimum, average and maximum data values of the AGC measuring field are collected. The AGC measuring field ranges in size from 25% to 80% of the entire image size.
- Minimum, average and maximum data values of the Image measuring field are collected. The Image measuring field is typically 95% of the entire image size.
- A rough histogram (16 bins) of the entire Image is also gathered.

Window / Level LUT

- The Window and Level LUT allows the contrast range of the image to be changed linearly. These user adjustments are often referred to as brightness and contrast adjustment similar to those found on the monitor.
- In the GoldOne the Window and Level function is accomplished using a lookup table. The Window and Level function can also be accomplished using addition and multiplication.
W/L/I (cont.)

W = width of window (Input axis) in DDLs mapped to the full output range

Note: In GoldOne product the Window value displayed on the screen on the User Interface and stored in the database is 1/2 W as defined above. Max window value is equal to 512 in GoldOne product.

L = Center of window (Input axis) in DDLs mapped to the full output range

Note: In GoldOne product the Level value displayed on the screen on the User Interface and stored in the database is equal to 1023 - L as defined above.

User Display LUT

- The User Display LUT feature is provided to allow the user to change the contrast presentation of the image to meet their own individual taste. Some users like a lot of contrast while others prefer a long gray scale presentation.
- In GoldOne the User Display LUT table is created from a number of cubic spline coordinates.

Invert

- In the GoldOne product the Window, Level, User LUT, and Invert functions are combined into a single hardware lookup table.
- It is important to place the Invert function in the proper order of processing.
The DICOM LUT is used to correct the transfer function of display devices (monitor, hardcopy, etc.) as defined by the DICOM standard.

Each different display device needs a corresponding DICOM LUT.

Auto Image Optimization (AIO)

Auto Image Optimization is accomplished by calculating the optimum Window/Level value and User LUT for each Image being displayed.

The Image statistics gathered on the image after the acquire LUT are used to calculate the optimized W/L and User LUT.

If histogram statistics are available the data is used in conjunction with the AGC average value to calculate the optimized User LUT.

A minimum Window value is specified to prevent flat field images from becoming too noisy.

AIO Window Calculations

\[
W = \frac{(\text{Image MF Max} - \text{Image MF Min}) \times \text{Max Window}}{\text{AIO Max Goal} - \text{AIO Min Goal}}
\]

\[
L = \frac{(\text{Image MF Max} + \text{Image MF Min})}{2}
\]
AIO User LUT (No Histogram)

MidPoint = (AGC MF Average - Image MF Min) * 1023
Image MF Max - Image MF Min

AIO USER LUT (w Histogram)

- Histogram information allows mid point calculation for the user LUT to exclude image data that most likely contains collimator blades, barium, and raw radiation from affecting the mid point calculation.
- The disadvantage of using histogram data occurs when the image statistics are only present in a small fraction of the bins. To overcome this disadvantage, the histogram data must be weighted based on the range of image statistics.

MidPoint = (AGC MF Average - Image MF Min) * 1023
Image MF Max - Image MF Min

Histogram Avg = \( n = 3 \)
\( n < 15 \)
Histogram[n] * ((n*64)+32
Histogram Total  = \( n = 3 \)
\( n < 15 \)
Histogram Total

MP Scale = (Image MF Max - Image MF Min) / 1023
Histogram MP = (Histogram Avg/ Histogram Total * MP Scale) + (MidPoint * (1 - MP Scale))
Further Enhancements

- Base the AIO goals on APRs or Doctor Profiles
- Different AIO goals based on Inverted/non-Inverted Images
- For Fluoro/Cine applications, incorporate feed forward AGC / Auto Black combined with AIO Techniques.
- Change the AGC Measuring Field size based on APRs setting.
- Auto Image Optimization on subtracted Spot Images in review.
- Add more Histogram bins.