Basics of Radiography Testing and Image Processing

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** BAM, Berlin, Germany

Preconference Workshop – 18 WCNDT, Durban, April 14, 2012
Structure of the Talk

• Basic Principle of Radiographic Testing
• Image formation in radiography and factors affecting radiographic image
• Need for Image processing
• Image parameters and terminologies
• Image Processing – Methods
• Applications on radiographic images
• Case Study
Radiography

116 yrs old – Technique is identical.
Improvements in sources and detectors.

Object placed between source and detector (film).

Differential absorption of radiation. \( I = I_0 e^{-\mu x} \)

The film darkness (density) will vary with the amount of radiation reaching the film through the test object.

= less exposure

= more exposure
### Sources

- Conventional (kV, mA)
- Microfocus
- Nanofocus
- Linac
- Betatron
- Synchrotron
- Isotopic Sources
  - Ir$^{192}$, Co$^{60}$, Tm$^{170}$, Yb$^{169}$, Cs$^{137}$, Se$^{75}$

### Detectors

- Film (D2.....D7)
- Image intensifiers
- X-ray sensitive vidicons
- Fluorescent screens + CCD
- Imaging Plates
- Digital Flat Panels
- Linear Diode Array
PARAMETERS AFFECTING RADIOGRAPHIC IMAGING

SUBJECT CONTRAST

FILM CONTRAST* DEFINITION

- ENERGY
- INTENSITY
- SCATTERED RADIATION
- FOCAL SPOT SIZE
- DETECTOR CHARACTERISTICS

MEASURED THROUGH SENSITIVITY

IMAGE QUALITY

SIGNAL TO NOISE RATIO

NORMALISED CONTRAST

BASIC SPATIAL RESOLUTION

TRADITIONAL APPROACHES - COMPENSATION PRINCIPLES
CONFIGURATION OF IMAGE PROCESSING SYSTEM

X-RAYS TRANSMITTED THR. OBJECTS

FILMS

REAL TIME SYSTEMS

DIGITAL DETECTORS

DIGITISER (SCANNER, A/D CONVERTOR, LUT)

A/D CONVERTOR, (LUT)

DIGITAL INTERFACE

COMPUTER + GRAPHICS CARDS + MEMORIES + DISPLAY DEVICES

DIGITAL RADIOPHGRAPIC IMAGE
DIGITAL IMAGE REPRESENTATION

IMAGES:
- Images - 2-D intensity function $f(x,y)$, $x$ and $y$: spatial coordinates and $f$: proportional to the intensity / brightness (gray level) of the image.
- Image Analog – Digital Image necessitates obtaining finite number of rows and columns and quantized levels.

DIGITAL IMAGE:
- It is a matrix with $M$ rows and $N$ columns. Each matrix element has a typical gray level value ranging from 0-255 (8 bit).
- Colour Image – three functions can be written as a vector valued function

$$ f(x, y) = \begin{bmatrix} r(x, y) \\ g(x, y) \\ b(x, y) \end{bmatrix} $$
IMAGE FORMATS AND TYPES

- Converting the acquired image into computer acceptable digitized from.
- Image can be of any of stored formats and image types.

 Stored formats

- TIFF (Tagged Image File Format)
- JPEG (Joint Photographic Expert Group)
- BMP (Windows Bitmap)
- XWD (X Windows Dump)
- PNG (Portable Network Graphics)
- GIF (Graphics Interchange Format)

 Image types

- Intensity image (data matrix with intensities scaled to represent gray scale)
- Binary Image (Logical array of 0’s and 1’s (only black and white))
- RGB image( three separate matrices (Red, Green and Blue))
EFFECT OF NUMBER OF PIXELS

16 X16  32 X 32  64 X 64  256 X 256  512 X 512  1024 X 1024

Digital Image Processing

Ewert et al.
July 2009
EFFECT OF GREY LEVELS

1 bit - 2 grey values
2 bit - 4 grey values
3 bit - 8 grey values
5 bit - 32 grey values
6 bit - 64 grey values
8 bit - 256 grey values
SPATIAL & GRAY LEVEL RESOLUTION

Image Resolution

Sum total of Pixel Resolution and Grey Level Resolution

**Number of Samples** determines **spatial resolution** of an image.
**Number of gray levels** determines **Gray level resolution** of an image.

**Subsampling** accomplished by deleting appropriate number of rows and columns but allowable gray levels maintained as 256.

Similarly, **pixel replication** brings all sub sampled images back to original size of 512*512.

**Drawback**: **Checker board pattern** will be more pronounced in 64*64 and 32*32 images respectively.

**Drawback**: **False Contouring** will be more pronounced in 16 or less uniformly spaced gray levels.
• **Image processing** refers to a set of operations performed to transform an existing image $f$ into new image $g$.

• We can transform either the range of $f$:

$$g(x, y) = t(f(x, y))$$

• Or the domain of $f$:

$$g(x, y) = f(t_x(x, y), t_y(x, y))$$
Primary purpose of image processing in radiology includes:

- Improvement image quality – making it more clear to human perception: improve sensitivity and contrast.
- Render minute details - finer defects can be identified.
- Precise Quantitative feature characterisation through enhancement of edges.
- Make data amenable for archiving and transmission.
- Render it amenable for automated defect recognition.
- Some argument about where image processing ends and fields such as image analysis and computer vision start.
DIGITAL IMAGE PROCESSING

Processes whose inputs and outputs are images in which we render detail more clearly and extract attributes from images up to and including the recognition of individual objects.

Image Compression (for effective storage & transmission)
Morphological Image Processing (image component extraction)

Wavelets & Multi Resolution Processing
Color Image Processing (operations in color domain)
Image Restoration (Recover image)
Image Enhancement (Highlight Region of Interest)
Image Acquisition

Knowledge base

Image Segmentation
Description (Quantitative characterization)
Object Recognition (assign label to objects)
**Image Processing Operations typical in RT**

**Image Processing**

- **Image enhancement**
  - Point Operations
  - Brightness
  - Contrast
  - LUT
  - Gamma value,
  - Histogram

- **Neighbourhood / Matrix operations**
  - Smoothing and Sharpness
  - statistical filters (Median, Max, Min)
  - directional filters
    - gradient filter
    - edge detection
Point Operations

Process in Spatial Domain is denoted by the expression

\[ G(x,y) = T[F(x,y)] \]

\( F(x,y) \) is Input Image, \( G(x,y) \) is Processed Image

\( T \) the operator applied at each location \((x,y)\) to yield output \( G \).

**Gray Level Transformation:**

\[ S = T(r) \]

The effect is to produce an image of higher contrast than the original by darkening the values of \( r \) below \( m \) and brightening the values above \( m \). This results in **Contrast Stretching**.

![Gray Level Transformation Diagram](image)
Contrast and Brightness Enhancement

Raw Image

Raw Image – After Brightness and Contrast Adjustment
Histogram Equalisation

\[ S_k = T(r_k) = \sum_{i=0}^{k} \frac{n_j}{n} \quad k = 0, 1, 2 \ldots L - 1, \ r_k \text{ is the kth gray level} \]

\[ n_k \text{ is the number of pixels in the image having gray level } r_k \]

The idea of histogram equalization is that the pixels should be distributed evenly over the whole intensity range, i.e. the aim is to transform the image so that the output image has a flat histogram.
Response R of a pixel is
\[ R = \sum w_i z_i \quad i=1, 2, \ldots, mn \]

Image divided into neighborhoods.

Sub images called filter or mask or kernel or template or window is applied on the neighborhood of the images.
Image Enhancement

Refers to highlighting region of interest in thermogram

Spatial domain analysis
(filter masks are applied on thermograms directly in spatial domain)

Frequency Domain analysis
(converting thermogram into frequency domain and then filter masks are applied)

Smoothing
(Highlights a portion of thermogram by blurring to remove noise)

Linear (Averaging, Gaussian filters) & Non Linear filters (Median, maximum and minimum filters)
(Spatial domain)

Butterworth, Gaussian and ideal Low pass filters
(Frequency domain)

Sharpening
(Highlights fine detail in thermogram)

Second order (Laplacian) & First order (Sobel, Prewitt and Roberts filters)
(Spatial domain filters)

Butterworth, Gaussian and ideal High pass filters (Frequency domain)
Smoothing

Original Image

P(i,j) = average [P(i,j), P(i-1,j-1), P(i+1,j+1), P(i+1,j-1), P(i-1,j+1)]

Smooth : Blurs the active image or selection. This filter replaces each pixel with the average of its 3 × 3 neighborhood.

Smoothened Image
Averaging filters

- Replace the gray level of the candidate pixel by the average gray level of the neighborhood pixels.
- Eliminate impulse noise and degradations appearing as thin stripes.
- Blur the image to get a gross representation of objects of interest as small deviations due to noise blend with the background while objects of interest are easy to detect.

![Fig. a Original Radiograph](image1)

![Fig. b Average filtered Radiograph](image2)

Averaging Mask

```
1 1 1
1 1 1
1 1 1
```

Weighted Averaging Mask

```
1 2 1
2 4 2
1 2 1
```

1/9

1/16
Sharpening Filters - Spatial Domain

- To highlight fine detail in an image or to enhance detail that has been blurred either in error or during image acquisition.

- Fine details result in discontinuities in an image such as points, edges and lines.

- Operator used must result in zero values at flat segments and non-zero at discontinuities.

- **First order derivative (Gradient operators)**
  - Mathematical equation: \( \frac{\partial f}{\partial x} = f(x+1,y) - f(x,y), \frac{\partial f}{\partial y} = f(x,y+1) - f(x,y) \)
  - Filter masks: Roberts, Sobel and Prewitt

- **Second order derivative (Laplacian operators)**
  - Mathematical equation: \( \frac{\partial^2 f}{\partial x^2} = f(x+1,y) + f(x-1,y) - 2f(x,y), \frac{\partial^2 f}{\partial y^2} = f(x,y+1) + f(x,y-1) - 2f(x,y) \)
  - Filter mask: Laplacian
Filtering – Noise Removal

Mean Filter (Matrix-mean)

Median Filter
Edge Enhancement

- Convolve filter
- Variance filter
- Band Pass Filter
- Unsharp mask
- High Pass Filter
Details of the Operations Performed on the Images

- **Media Filter**: Reduces noise in the active image by replacing each pixel with the median of the neighboring pixel values.
- **Mean Filter**: Smooths the current image by replacing each pixel with the neighborhood mean.
- **Minimum Filter**: Filter does grayscale erosion by replacing each pixel in the image with the smallest pixel value in that pixel’s neighborhood.
- **Maximum Filter**: Filter does grayscale dilation by replacing each pixel in the image with the largest pixel value in that pixel’s neighborhood.
- **Gaussian Blur**: Filter uses convolution with a Gaussian function for smoothing.
- **Convolve**: Does spatial convolution using a kernel entered.
- **Unsharp Mask**: Sharpens and enhances edges by subtracting a blurred version of the image (the unsharp mask) from the original.
- **Variance Filter**: Highlights edges in the image by replacing each pixel with the neighborhood variance.
- **Bandpass Filter**: Removes high spatial frequencies (blurring the image) and low spatial frequencies (similar to subtracting a blurred image). It can also suppress horizontal or vertical stripes that were created by scanning an image line by line.
Case Study -1
In-service Inspection – Power Plant Life Extension

Sodium blockage in a hot argon communication line of Fast Breeder Test Reactor at Kalpakkam. Reactor shut down. Detection became critical.

Low density material. Gamma source – Ir 192.

Challenge – Limited access, large area, low Z material. Very low contrast radiograph.

Approach - Advanced Image processing:
Contrast Stretching, Noise Removal, Sharpening - Edge Enhancement
Case Study – 2  Enhancement of Tenon Rivet Head in HP Rotor of MAPS Unit -1 Turbine Generator

Power Station in India shutdown (as part of bi-annual maintenance) and Turbine Generator was opened for in-service inspection. During in-service visual inspection, the thickness of rivet head of tenon of blade 17 of HP rotor stage-2 was found to be less than other blade tenons and almost flush with shroud. Regulators wanted proof.

Low Contrast radiograph by Gamma Radiography

Filtered and contrast enhanced image. Note that the edges of the rivet head can be seen as sharp points over the shroud portion.

Approach – Denoising + Deblurring + Gaussian Filter + bandpass filter + contrast enhancement and profiling
Edge Enhancement through Spatial filtering

Case Study - 3 : Quality Assurance of small diameter 0.5 mm - Thermocouple used in nuclear reactors

ASTM Standard + Image Enhancement = Enhanced Interpretation and Quantitative Evaluation for weld quality, sheath spacing, uniformity of insulation material filling


COMBINING ADVANCED CONCEPTS WITH STANDARD PRACTICES FOR ROBUST QUALITY ASSURANCE
Thank You