Development of Radiographic Image Processing Algorithms at CNL

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Advantages of Digital Radiography

The main advantages of Digital Radiography (DR) can be summarised as:

- Improved latitude in comparison to classical film radiography. The direct improvement in the visible thickness range for steel is typically up to five times, with additional improvement of up to three times when combined with digital image processing.
- Significant reduction in test and interpretation time.
- Overall improved radiation safety, including reduction of the exclusion zone and the exposure rate to personnel.
- Elimination of the chemical processing.
- Operational cost savings and improved decision-making process.
- Two main types of Digital Radiography systems:
  - Computed Radiography (CR), based on flexible imaging plates, direct replacement of films, wider latitude and less sensitive than FP detectors
  - Flat-Panel (FP) pixel detectors, faster and offer better SNR and CNR

Advantages of Image Processing

- Digital image processing can improve the visible thickness range by a factor of up to five (5) times, which effectively improves the latitude and the visibility of radiography through thick objects.
- Digital image processing can employ algorithms for noise reduction and image enhancement, and can improve contrast, sensitivity, signal-to-noise ratio (SNR), and contrast-to-noise ratio (CNR).
- Digital images are very easy to communicate, can be sent immediately (without film processing) for interpretation and decision making, with the person making the image interpretation being at a completely different location.
- Because the digital radiography images can be instantaneous, they can be used for observation of moving parts in real time.

Description of the Software

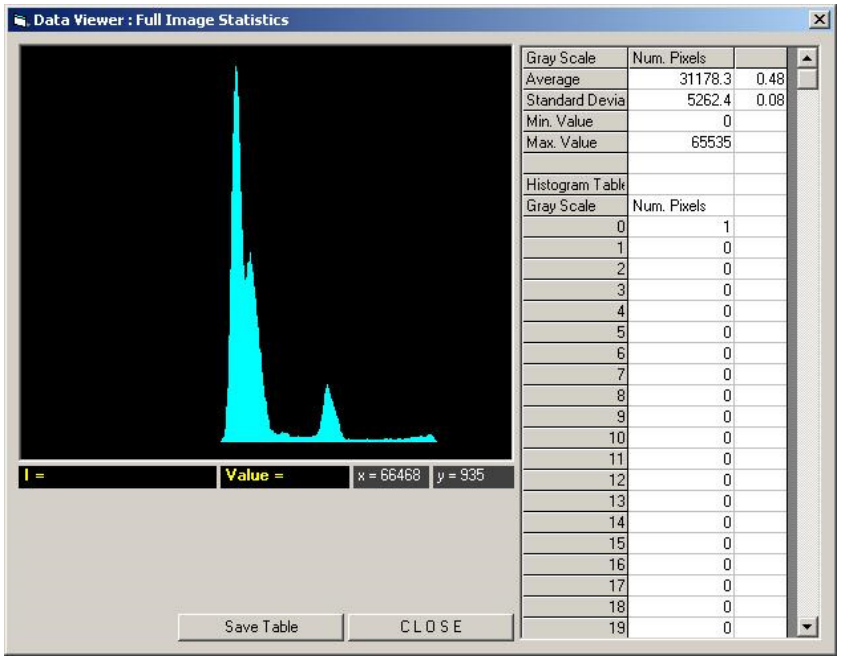
There are three main regions in the CNL Image Processing Tool IPT:

(1) menus,
(2) control buttons, and
(3) display area.

Description of the Software

All basic editing, transforming, image manipulating, and I/O functions are implemented:

- Read/Write images
- Zoom/Magnifying Glass
- Invert, Rotate, Flip
- Filtering (Average, Median, Gaussian, Min/Max, Emboss, etc.)
- Intensity stretching
- Brightness, Contrast, and Gamma adjustment
- Select, Copy, Crop, Paste, Duplicate
- Line profile
- Histogram display
- Histogram equalization



Advanced Image Processing Algorithms

Advanced image processing algorithms in the following groups were developed:

- Methods for image noise suppression.
- Methods for image contrast enhancement.
- Methods for image grey-scale manipulation.
- Methods for statistical image analysis.
- Methods based on Fast Fourier Transform (FFT)
- Methods based on Discrete Wavelet Transform (DWT)

Methods for image noise suppression

Two-dimensional bilateral smoothing takes into account both the closeness of the pixels (i.e., distance) and similarity of the pixels (i.e., intensity).

$$S_1(i,j) = \sum_{k=-M}^{M} \sum_{m=-M}^{M} A(i+k, j+m) \cdot Y(i+k, j+m)$$

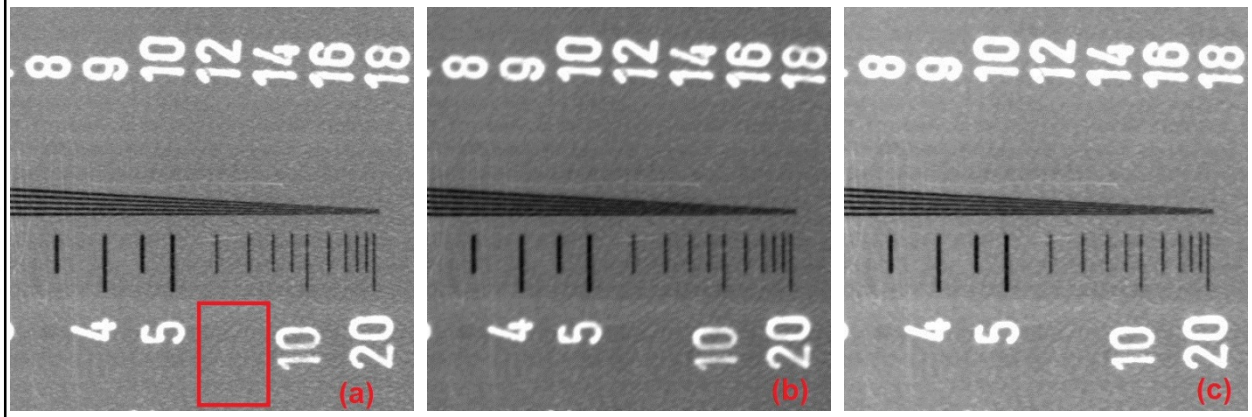
$$A(i+k, j+m) = e^{-\alpha_1 \left(\frac{|\mu_Y(i,j) - \mu_M(i,j)|}{\sigma_M(i,j) + \sigma_Y(i,j)} \right) (k^2+m^2)} \cdot e^{-\alpha_2 \frac{|Y(i+k,j+m) - \mu_Y(i,j)|}{\sigma_Y(i,j)} \frac{|Y(i+k,j+m) - Y(i,j)|}{|\mu_Y(i,j) - \mu_M(i,j)|}}$$

$$\vdots$$

$$A(i+k, j+m) = \frac{1}{\left(1 + \frac{[Y(i+k,j+m) - Y(i,j)]^2}{\sigma_1^2}\right)} \cdot \frac{1}{\left(1 + \frac{(k^2+m^2)}{\sigma_2^2}\right)}$$

Comparison of different smoothing algorithms.

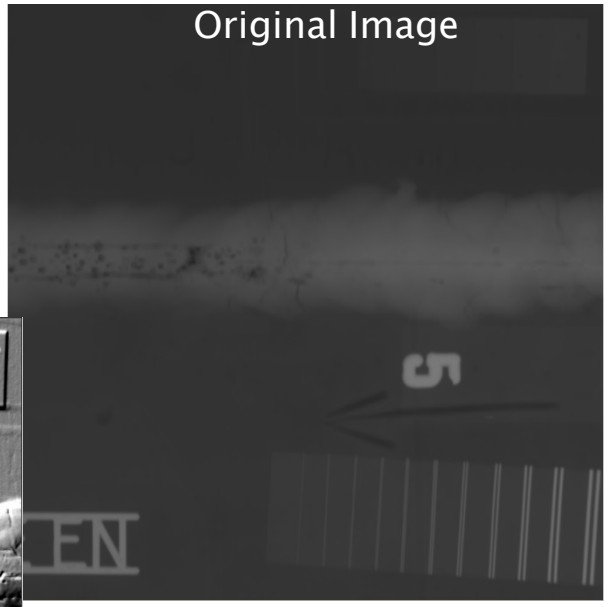
Image	SNR	Spatial Resolution [LP/mm]	Filter Parameters
Original	17.4	9	
Selectable Filter 5x5 (Average)	30.7	4.5	
Selectable Filter 7x7 (Gaussian)	25.1	7	
Polynomial Smoothing	27.1	6	F1, 2, 2
Original Bilateral Smoothing	29.3	8	3, 3, 0.05
New Bilateral Smoothing Eq. (1)	23.7	8	1, 0.1, 3, 0.1
New Bilateral Smoothing Eq. (2)	25.1	9	1, 0.1, 3, 0.4
New Bilateral Smoothing Eq. (3)	22.6	9	1, 0.2, 3, 1
New Bilateral Smoothing Eq. (4)	19.0	8	1, 0.2, 3, 0.5
New Bilateral Smoothing Eq. (5)	19.0	7	1, 3, 1
New Bilateral Smoothing Eq. (6)	18.5	8	1, 3, 0.001
New Bilateral Smoothing Eq. (7)	21.8	8	1, 2, 1
New Bilateral Smoothing Eq. (8)	27.3	8	3000, 3, 1
New Bilateral Smoothing Eq. (9)	33.6	6	3000, 3, 1
New Bilateral Smoothing Eq. (10)	25.1	9	1, 3, 2
New Bilateral Smoothing Eq. (11)	22.6	8	1, 0.1, 3, 3
New Bilateral Smoothing Eq. (12)	34.5	5.5	1, 3000, 3, 1



(a) original image, (b) polynomial smoothing, and (c) bilateral smoothing

Methods for image noise suppression

Smoothing and differential operators based on fitting with orthogonal polynomials.



Note: Due to the limited contrast for images in PPT and PDF files, the original image looks darker in comparison to the case when viewed on professional radiography monitor. Nevertheless, the improvements demonstrated in this presentation cannot be achieved with simple intensity and brightness adjustments of the original image.

Following recurrence formulae for generating orthogonal polynomials were used:

$$T_{n+1}(i,j) = (i + j - a_n).T_n(i,j) - b_n.T_{n-1}(i,j)$$

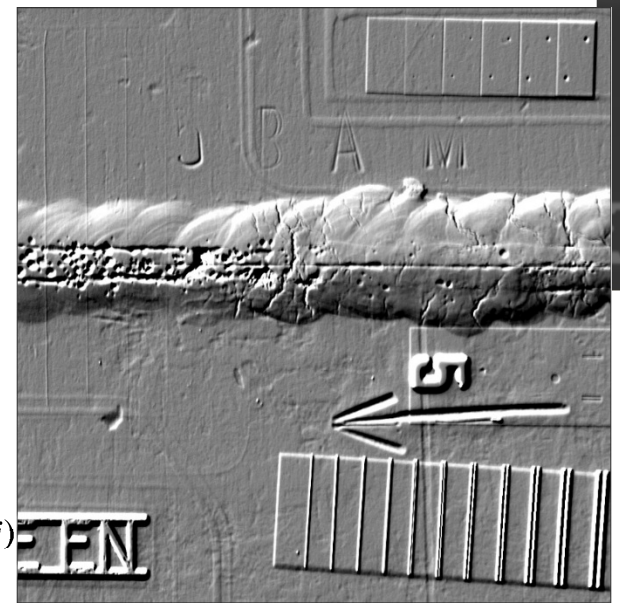
$$T_{n+1}(i,j) = (i^2 + j^2 - a_n).T_n(i,j) - b_n.T_{n-1}(i,j)$$

$$T_{n+1}(i,j) = (\sqrt{i^2 + j^2} - a_n).T_n(i,j) - b_n.T_{n-1}(i,j)$$

$$T_{n+1}(i,j) = (|i| \cdot |j| - a_n).T_n(i,j) - b_n.T_{n-1}(i,j)$$

$$T_{n+1}(i,j) = (|i| + |j| - a_n).T_n(i,j) - b_n.T_{n-1}(i,j)$$

$$T_{n+1}(i,j) = (i + j + i \cdot j - a_n).T_n(i,j) - b_n.T_{n-1}(i,j)$$



The smoothed derivatives operation combines noise suppression with visibility enhancement, and can be useful for simultaneous observation of objects with different thickness in the radiographs.

Methods for Image Contrast Enhancement

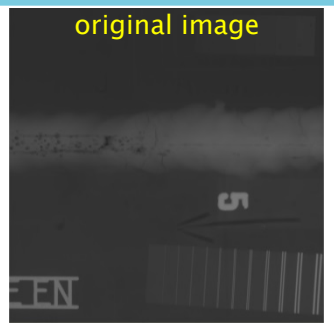
Algorithms for the following contrast enhancement methods were developed:

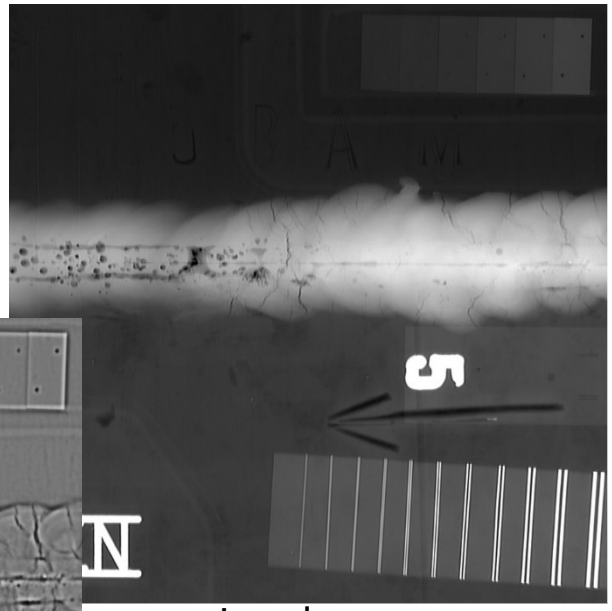
- Sharpening filters (17 sharpening filters with selectable parameters were implemented),
- Local contrast enhancement algorithms,
- Adaptive unsharp mask algorithms,
- Adaptive contrast enhancement.
- Contrast enhancement by digital equalization (CEDE)

$$Y_1(i,j) = \mu_M(i,j)$$

$$S_2(i,j) = 1 + 65534.\frac{[Y(i,j) - \mu_N(i,j)] + 65535}{131070}$$

(only high-frequency part of the image)

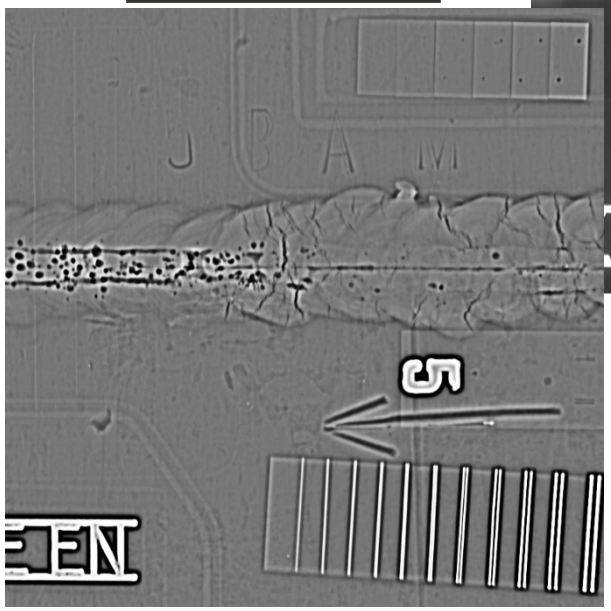




Local contrast enhancement

(merge low and high frequency parts)

$$S_2(i,j) = 1 + 65534.\frac{[\alpha_1.Y_1(i,j) + \alpha_2.Y_2(i,j)]}{65535.(\alpha_1 + \alpha_2)}$$

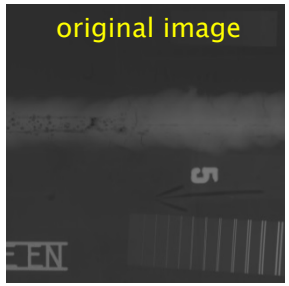


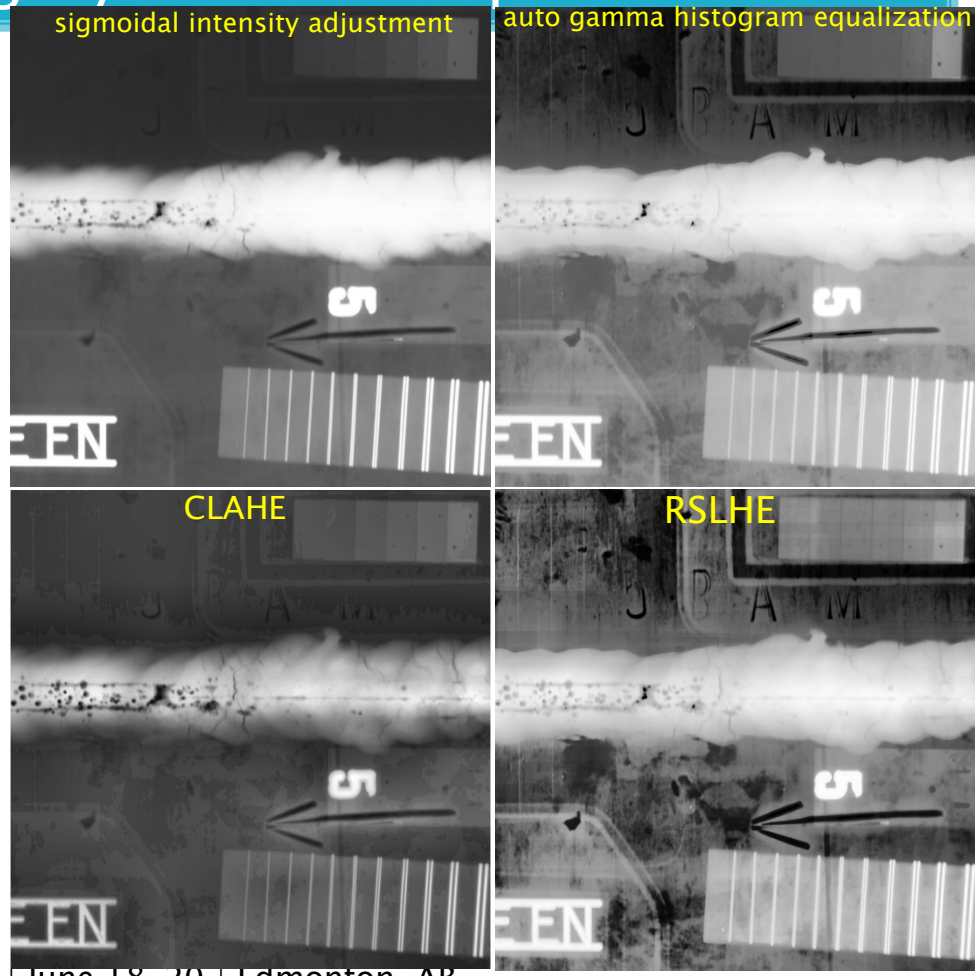
CEDE

Methods for image grey-scale manipulation

Algorithms for the following grey-scale methods were developed:

- Sigmoidal intensity adjustment with multiple types of functions.
- Auto sigmoidal intensity adjustment.
- Auto gamma histogram equalization.
- Local histogram equalization.
- Contrast limiting adaptive histogram equalization (CLAHE)
- Random sampling local histogram equalization (RSLHE)
- Local intensity stretching with bi-linear interpolation (LISBLI)
- Local intensity rank filtering

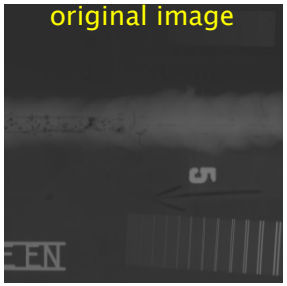


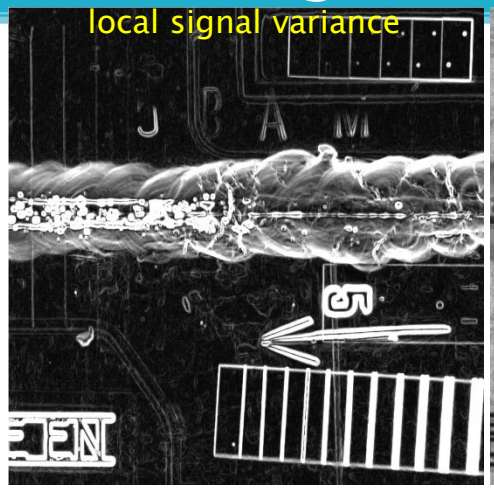


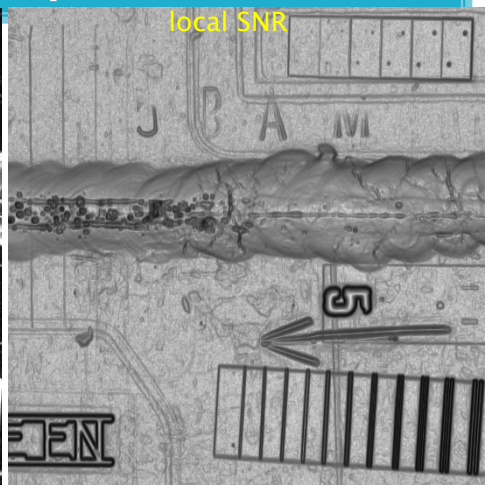
Methods for statistical image analysis

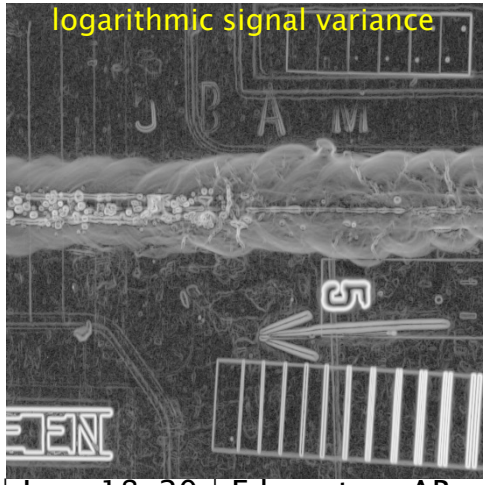
Image processing methods, based on calculation of different local statistical parameters, were developed and implemented:

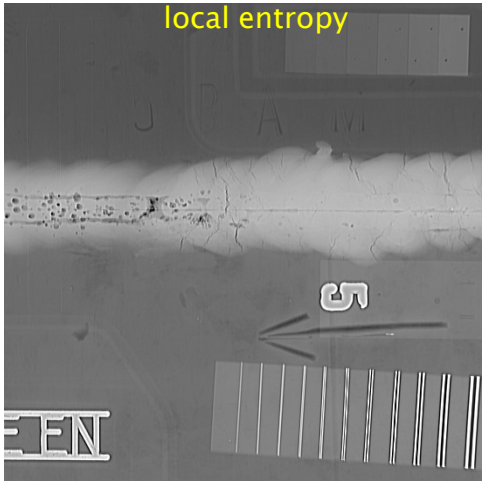
- signal variance,
- entropy,
- adaptive histogram entropy,
- signal-to-noise ratio,
- contrast-to-noise ratio









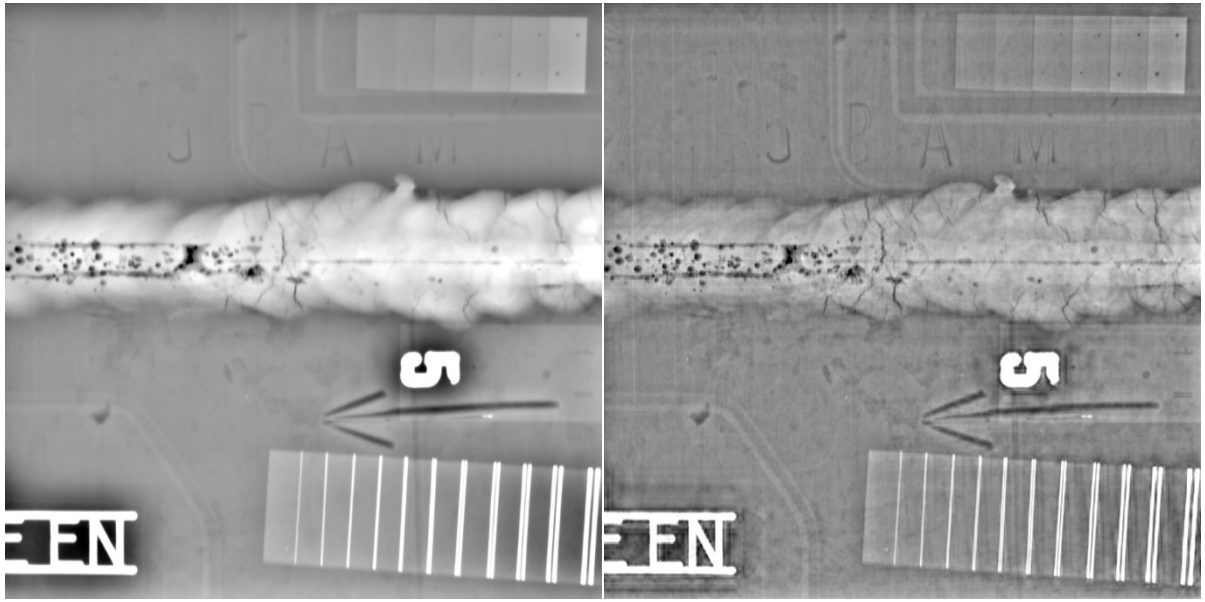


FFT and DWT based methods

The Fourier transform is based on sine and cosine functions which have infinite range in the space domain, but they are completely localized (δ-functions) in the frequency domain.
The wavelet transform uses basic functions which are localized both in the space domain and in the frequency domain. Two types of filtering of the input image were developed using DWT:

- a low-pass filter (or convolution with a smoothing function)
- a high-pass filter (or convolution with a differentiating function).

Separately, two multi-scale enhancement algorithms were developed and implemented, based on application of different enhancement function for details coefficients of the different decomposition levels.



FFT band-pass filtering (left), and multi-level DWT based image processing (right).

Conclusions

- Advanced image processing methods can bring noticeable improvement in the visibility and detection of details in the radiographic images.
- CNL has developed a prototype image processing software, and has developed and implemented several advanced image processing methods in the following groups:
  - Methods for image noise suppression.
  - Methods for image contrast enhancement.
  - Methods for image grey-scale manipulation.
  - Methods for statistical image analysis.
  - Methods based on Fast Fourier Transform (FFT)
  - Methods based on Discrete Wavelet Transform (DWT)
- The developed software platforms can be used for further research work in the field of radiography image processing and for the development and testing of new image processing algorithms.
- It would be useful for the radiographic community to generate several standardized digital radiography images, which can be used for testing radiographic image processing methods and software.
- The path forward is to organize a round-robins of image processing programs.

Conclusions

It is important to note that any image processing software should be considered only as an aid to the analyst for interpretation and flaw-sizing of the digital images, which greatly improves the probability of detection of flaws in the radiographs. Any indication detected in the enhanced radiograph should be confirmed with simple intensity stretching (this is equivalent to changing intensity of the radiographic film viewer). ASME code allows for image processing of the digital radiographs, but only indications that are confirmed by simple image intensity stretching should be reported. The following are excerpts from ASME code:

> *"…The digital image shall be interpreted while displayed on the monitor. The interpretation may include density and contrast adjustment, quantification, and pixel measurement, including digital or optical density values and linear or area measurement. The interpretation of a digitized image is dependent upon the same subjective evaluation by a trained interpreter as the interpretation of a radiographic or radioscopic image. … After the interpretation has been completed, the interpretation data and the digital image, which shall include the unprocessed original full image and the digitally processed image, shall be recorded and stored. … signal processing parameters — including density shift, contrast stretch, log transform, and any other techniques that do not mathematically alter the original digital data, e.g., linear and area measurement, pixel sizing, and value determination."*

Questions?

Thank you. Merci

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