Comparison of Radiographic Image Processing Algorithms

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ABSTRACT

Several different image processing methods are described and discussed. Their applicability to the processing of images from digital radiography equipment is compared. The overall conclusion is that advanced image enhancement methods are beneficial and can improve detectability of flaws in digital radiography images, but that these enhancement methods have to be used carefully, especially in cases when digital radiography is used under the restrictions of ASME code requirements. In these cases, the indications detected in the enhanced digital images have to be confirmed by simple intensity stretching, equivalent to changing the intensity of the radiographic film viewer, in order to avoid reporting artifacts which could be produced by the image processing procedure itself.

INTRODUCTION

Digital radiography (DR) can be used for fast and reliable inspection and diagnostics of a variety of objects (welds, pipes, valves, walls, etc.) made from different materials (metal, plastic, wood, concrete, etc.). It offers improved detector dynamic range in comparison to classical film radiography. The main advantage arising from the use of DR will be a faster and improved decision-making process regarding the status of the inspected object, and the associated improvements to quality and/or operation of corresponding systems, which could translate into significant savings.

Image processing is very important to digital radiography, because it allows for significant enhancement of the visibility of the details in the digital radiographs. Different image processing software packages are available, both commercial and open-source. Some of them are specialized radiography image processing programs, supplied together with the radiography inspection systems, while others are general

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purpose image processing software. It is important to compare capabilities of the different image processing software packages in two areas: (i) evaluation of the minimum Image Quality Indicator (IQI) feature in the enhanced image, and (ii) evaluation of artifacts introduced by the enhancement method.

This report evaluates the applicability of several available software packages and compares different techniques for processing digital radiography images.

SOFTWARE OPTIONS FOR RADIOGRAPHY IMAGE PROCESSING

There are several different approaches to selecting image processing software for digital radiography:

- The first approach is to use some of the freely available image processing software packages, and to test them to see if they can be used for processing digital radiography images. Although these software packages are free, they are usually developed by respected institutes or organizations, have a large user/support base, and can be considered professional software.
- The second approach is to study and compare the commercially available radiography image processing software packages. Unfortunately, some of these packages are available only embedded with radiography systems.
- The third approach is to select an appropriate software development platform and tools, and to develop in-house radiography image processing software.

This paper will focus on the first two approaches, and only briefly discuss the third approach.

REQUIREMENTS FOR IMAGE PROCESSING SOFTWARE

In order to facilitate the selection and comparison of different image processing options, it is necessary to specify the "user" requirements for the software. Based on our current experience, we have developed the following list of requirements for digital radiography image processing software:

- *Image file-format requirements*. The selected and/or developed software should be able to support (i.e., read, write, and internally represent), as a minimum, 16-bit and 8-bit images in TIF, BMP, and JPG formats.
- *Image editing requirements*. The selected and/or developed software should be able to support, as a minimum, basic image editing functions such as: select line and rectangle, crop, cut, paste, duplicate, rotate, flip, zoom, undo.
- *Image manipulation requirements*. The selected and/or developed software should be able to support, as a minimum, basic image manipulation functions such as: inversion, brightness and contrast adjustment, intensity stretching, histogram calculation, line profile calculation, area statistics calculation.
- *Image transformation requirements*. The selected and/or developed software should be able to support, as a minimum, basic image transformation functions such as: image despeckling, log transformation, standard smoothing filters (like median and average), standard enhancing filters (like sharpening, edge detection, unsharp mask, gradient, Laplacian, Sobel, and Prewitt).
- *Radiography requirements*. The selected and/or developed software should have one or more of the following capabilities:

    - *advanced noise suppression algorithms*. These algorithms can be based on Fourier/Wavelet transforms or on different adaptive digital filters.
    - *advanced image contrast enhancement algorithms*. These include algorithms based on frequency domain filtering (Fourier and/or wavelets transform) or based on localized adaptive contrast enhancement. Since the wide range of thickness variation in a radiographed object leads to a wide range in grey-scales in the radiographic image, it is important to visualize and observe simultaneously the whole thickness range recorded in the radiographs in order to perform proper diagnostics of the object being tested. The human eye can distinguish only about 32 different grey-levels, so it is impossible to observe internal details in the radiographed object without application of appropriate image enhancement techniques. This requires strong image enhancement algorithms and advanced visualization methods to be available in the image processing software.
    - *advanced grey-scale manipulation algorithms*. Most of these algorithms are based on global or localized histogram equalization, or on other advanced methods like differential hysteresis filtering.
- *Capabilities for implementation of new algorithms*. The selected and/or developed software should be able to support, by means of macros, plug-ins, or changes, the implementation of new advanced image processing techniques.

COMPARING FREE IMAGE PROCESSING SOFTWARE

The first step was to select and compare several free image processing programs. There are several high-quality free image processing software packages available:

- **ImageJ** (http://rsb.info.nih.gov/ij/). This software was developed by the National Institute of Health (NIH), and is used mainly for image processing in the medical field, including image processing of radiological images. This software is platform independent (Java based) and allows for macros and "plug-ins" to be developed and added to it.
- **IRIS** (http://www.astrosurf.com/buil/us/iris/iris.htm). This is image-processing software specifically developed for processing astronomical images.
- **IrfanView** (http://www.irfanview.com/). This is general purpose image-processing software.
- **XnView** (http://www.xnview.com/). This is another general purpose image-processing software.

All of the above software packages were downloaded and installed, and were used for processing of test images in order to evaluate and compare their capabilities. ImageJ had largest variety of options and was the only free software package which met all requirements. It is (in the opinion of this author) the most appropriate free software for radiographic image processing.

Further evaluation of the capabilities of ImageJ was done in order to quantify the limits of its use. A test image of a weld with several penetrameters was used to compare different image processing techniques. The comparison included two parts:

- The first was qualitative, i.e., subjective evaluation of the overall quality and visibility of the image.
- The second was quantitative, i.e., evaluation of the smallest visible indicator for each penetrameter.

The first step was an evaluation of available advanced image processing techniques for 8-bit images. The results for the different image processing techniques (smallest visible wire, hole, and resolved double-wire) are summarized in Table 1. The parameters used for the different image enhancement methods are shown in parenthesis. Yellow boxes are for cases when the processed image is worse than the original (i.e., one can see smaller features in the unprocessed image), and green boxes are for cases when the processed image is better than the original.

Table 1. Comparison of image enhancement methods for ImageJ (8-bit processing).

Image-processing type	Double Wire IQI	Wire IQI	Step-Hole IQI	#5 Hole IQI			Subjective Overall Visibility Rank
				1T	2T	4T	
Original 16-bit image	#8	#5	#3	N	Y	Y	
Anisotropic Diffusion Filter (20, 10, 0.05)	#6	-	#4	N	Y	Y	
Contrast Enhancement Filter (3)	#10	#4	#3	N	N	Y	
Contrast Enhancement Filter (5)	#10	#4	#3	N	Y	Y	
Contrast Enhancement Filter (7)	#9	#4	#3	N	Y	Y	2
Contrast Enhancement Filter (9)	#9	#5	#3	N	Y	Y	1
Haar Wavelet Filter (12, 3,0)	#6	#3	#3	N	Y	Y	
Lipschitz (15, TopDown) - Original (inverted)	#9	#5	#3	N	Y	Y	5
Original - Haar Wavelet Filter(3, 2, 1)	#8	#4	#1	N	N	N	
Original - Trous Wavelet Filter (4, 2, 1, 0, 0)	#10	#6	#4	N	Y	Y	
Original - Trous Wavelet Filter (4, 3, 2, 1, 0)	#10	#5	#3	N	Y	Y	
Original - Trous Wavelet Filter (8, 2, 0.5, 0, 0)	#10	#5	#4	N	Y	Y	4
Original - Trous Wavelet Filter (8, 3, 1, 0, 0)	#10	#5	#3	N	Y	Y	
Original - Trous Wavelet Filter (8, 4, 2, 0, 0)	#10	#5	#2	N	Y	Y	
Original - Trous Wavelet Filter (8, 4, 2, 1, 0)	#10	#5	#2	N	Y	Y	
Original - Trous Wavelet Filter (8, 6, 4, 2, 1)	#9	#5	#4	Y	Y	Y	
Original - Trous Wavelet Filter (12, 9, 3, 1, 0)	#5	#5	#4	Y	Y	Y	3
Original - Trous Wavelet Filter (16, 8, 4, 2, 1)	#5	#5	#4	Y	Y	Y	

As can be seen, even 8-bit image processing can improve visibility of the image details. It is also important to be noted that there is no universal image processing filter, i.e., processing parameters for some of the image enhancement filters were optimized for the selected test image, but this will not guarantee that the same filters will be optimal for other images. Another important observation is that image processing techniques can introduce artifacts in the final image, which could lead to miss-interpretation of the results. This means that any detected feature in the enhanced radiograph should be confirmed with simple intensity stretching of the original image.

Another evaluation of the image processing techniques available in ImageJ was done using radiography of a valve as a test image. A valve was selected because it has a wide range of thickness variation, which manifests itself as a very wide range in grey scales in the radiographic image. This is considered to be a difficult image for simultaneous visualization of all internal and external features. Very good visibility of details was achieved with a Fourier-Transform (FFT) bandpass filter after image inversion and log transformation. Wavelet Filter and Ranking filter are implemented in ImageJ only for 8-bit images, so the valve test image was first transformed to an 8-bit image, and after that was processed. Although wavelet filters have very good noise suppression properties and are very good for processing radiographic images of welds, the ImageJ implementation did not provide full multi-scale capability and did not provide good visibility of details for valve radiography.

The second step was to evaluate the 16-bit advanced image processing techniques available in ImageJ. The results for the different image processing techniques are summarized in Table 2 (for a weld test image). Both negative and positive images of the original weld radiograph were processed and evaluated. As can be seen, significant improvement in the visibility of the details in the radiographs can be achieved with some of the image processing methods used.

Table 2. Performance of ImageJ's 16-bit image processing techniques.

Image-processing type	Double Wire IQI	Wire IQI	Step-Hole IQI	#5 Hole IQI			Subjective Overall Visibility Rank
				1T	2T	4T	
ImageJ, 16-bit processing, negative image							
Original 16-bit image	#8	#5	#3	N	Y	Y	3
Normalized, Equalized, Unsharp Mask	#8	#7	#4	Y	Y	Y	2
Normalized, FFT Bandpass Filter (80, 1), Normalized, Equalized, Unsharp Mask	#6	#7	#5	Y	Y	Y	1
Normalized, Anisotropic Diffusion 2D (20, 1, 20, 0.1, 0.9, 30, 1)	#8	#3	-	N	N	N	4
ImageJ, 16-bit processing, positive image							
Inverted, Normalized	#8	#3	#2	N	Y	Y	3
Inverted, Normalized, Log-transform, Normalized, Equalized, Unsharp Mask	#9	#7	#3	Y	Y	Y	2
Inverted, Normalized, FFT Bandpass Filter (80, 1), Normalized, Equalized, Unsharp Mask	#7	#7	#5	Y	Y	Y	1

COMMERCIAL SOFTWARE FOR RADIOGRAPHY IMAGE PROCESSING

The second task was to evaluate the available commercial radiographic image processing software packages. Usually each digital radiography system is shipped with radiography image processing software, which includes basic image manipulation functions and authoring and archiving tools (usually database based). Most of the advanced image processing algorithms for radiography were initially developed for medical applications, and, after that, transferred to Non-Destructive Examination (NDE) applications. In most cases, one cannot buy the image processing software separately, but rather must buy the whole digital radiography system.

When we were studying the available commercial radiographic image processing software packages, we considered the following requirements:

- The software should offer all basic image manipulation options listed above.
- The software should offer at least one advanced image processing method.
- The software should be available as a stand-alone software package, i.e., one should be able to buy the software without purchasing a complete digital radiography system.

Comparison of some of the available software packages for digital radiography is presented in Table 3, based on manufacturer information about their capabilities. For some of the commercially available software packages, it was impossible to determine if they offer advanced image enhancing methods, based only on their description.

Table 3. Comparing commercial software for Industrial Radiography.

Company	Software	Image Enhancing Method	Notes
AllPRO Imaging	Visix	-	
	Metron	-	
GE/AGFA	Rhythm/MUSICA	Wavelet based	
Yxlon International	Y. Image 3500	-	
	Y. Image 4500	-	
VJ Technologies	Vi3	ADE based	with System only
Duerr	DBSWIN 3.X	-	with System only
KODAK	INDUSTREX DVS v3.0		with System only
Fujifilm	DynamIX	-	with System only
Sentinel	Vision HR	FFT Based	with System only
NTB X-Ray Imaging	iX-Pect	-	with System only
VisiConsult GmbH	XplusFPD7	-	with System only
Image Content Technology	LUCIS	Differential Hysteresis	General Purpose Software
Facor	FACOR	FACOR filters	Needs integration

The Rhythm software from GE Inspection Technologies (also known as MUSICA from AGFA) uses wavelet-based multi-scale image enhancement technology. As can be seen from the posted examples (e.g., http://www.ge-mcs.com/en/ndt-software/rhythm-software-suite/rhythm-radiography.html), the visibility of details can be greatly enhanced using Rhythm image processing software.

Another technology for image enhancement is available from VJ Technologies. Their Vi3 digital radiography software incorporates patented technology called Advanced Defect Enhancement (ADE), which also provides significant enhancement of the visibility of internal details in the radiographed object. Examples of images enhanced with Vi3 are available at http://www.vjt.com/Vi3_Imaging Software.html.

Another promising image processing technology is the LUCIS software based on a patented differential hysteresis method. This software is for general image processing, but it can be used off-line for processing radiographic images. Examples of enhanced visibility of details with the LUCIS software can be found at www.lucispro.com.

FACOR filters are used for processing medical radiography images and have good image enhancement properties. FACOR filters are provided as a software development tool, and were integrated in our prototype image processing software. These filters have a scripting description of the selected image processing, which allows for a wide range of customer-specific filters to be implemented and adjusted for the specific image processing task. Examples of medical radiography images processed with the FACOR filters are available at http://www.facor.info/xray.htm.

The performance of the different 16-bit FACOR filters, incorporated into our image processing software, was evaluated using the weld test image. The results are summarized in Table 4. The overall visibility of the details was improved, but in some cases the resolution of the details was reduced. This suggests that FACOR filters have to be used carefully, and optimized for each type of examined object.

Table 4. Performance of the different 16-bit FACOR filters.

Image-processing type	Double -Wire IQI	Wire IQI	Step-Hole IQI	#5 Hole IQI			Subjective Overall Visibility Rank
				1T	2T	4T	
FACOR, negative image							
Original 16-bit image	#8	#5	#3	N	Y	Y	
Facor Filter #0147	#6	#5	#3	Y	Y	Y	
Facor Filter #0148	#6	#5	#3	N	Y	Y	1
Facor Filter #0472	#5	#5	#3	N	Y	Y	
Facor Filter #2000	#8	#6	#4	Y	Y	Y	2
Facor Filter #2001	#8	#3	#1	N	N	N	
Facor Filter #2180	#9	#7	#5	Y	Y	Y	3
Facor Filter #2181	#8	#6	#4	Y	Y	Y	
Facor Filter #2403	#8	#5	#3	N	Y	Y	
Facor Filter #2604	#8	#5	#3	N	Y	Y	4
Facor Filter #5000	#5	#5	#3	N	Y	Y	
Facor Filter #5300	#5	#5	#3	N	Y	Y	
FACOR, positive image							
Inverted, Normalized	#8	#3	#2	N	Y	Y	
Inverted, Normalized, Facor Filter #0147	#5	#2	#1	N	Y	Y	
Inverted, Normalized, Facor Filter #0148	#5	#3	#2	N	Y	Y	4
Inverted, Normalized, Facor Filter #0472	#5	#2	#1	N	N	N	
Inverted, Normalized, Facor Filter #2000	#8	#4	#2	N	Y	Y	2
Inverted, Normalized, Facor Filter #2001	#7	#2	#1	N	N	N	
Inverted, Normalized, Facor Filter #2180	#9	#5	#4	Y	Y	Y	1
Inverted, Normalized, Facor Filter #2181	#8	#4	#3	N	Y	Y	
Inverted, Normalized, Facor Filter #2403	#8	#3	#2	N	N	Y	
Inverted, Normalized, Facor Filter #2604	#6	#5	#2	N	Y	Y	3
Inverted, Normalized, Facor Filter #5000	#5	#2	#1	N	N	Y	
Inverted, Normalized, Facor Filter #5300	#5	#2	#1	N	N	Y	

AECL IMAGE PROCESSING SOFTWARE

AECL has started the development of image processing prototype software, to be used for implementation and testing of new image processing algorithms. At the current stage, all basic editing and image manipulation functions are implemented, and work is underway on the development of advanced image processing algorithms and their implementation. Examples of currently implemented advanced image processing techniques are: an integrated line profile tool; a statistical image quality evaluation tool; methods for statistical mapping of the image; polynomial and adaptive smoothing; interactive non-linear histogram adjustment; adaptive contrast enhancement; FFT and Wavelet based image enhancement methods, etc. Full description and evaluation of the image processing prototype software and the developed new image processing methods are outside the scope of the current paper, and will be presented in future publications.

CONCLUSIONS AND DISCUSSION

Several image processing software packages and techniques were investigated and compared, including several commercially available software packages. From the free image processing software programs, ImageJ can be recommended as promising stand-alone image processing software, which allows for easy implementation of macros and new plug-ins, and can be customized to fit the need of radiographic image processing. Several commercial software packages, like Rhythm and Vi3, incorporate advanced image processing methods, but some of them are only available as part of a whole digital radiography system. In all cases, if commercial digital radiography image processing software is purchased, it has to be customized to fit the need of each laboratory. Another approach is to develop in-house image processing software, which also can be used for evaluation of third-party image enhancement tools and for testing new image processing algorithms.

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. Any indication detected in the enhanced radiograph should be confirmed with simple intensity stretching (this is equivalent to changing the intensity of the radiographic film viewer), as per ASME code [1] requirements. Only indications that are confirmed in this way should be reported. The reason for this is to avoid reporting artifacts which could have been produced by the image processing procedure itself. Using free image processing software like ImageJ, or in-house software, or even using commercial software for radiographic image processing, would require an extensive validation process, if the software is to be used for ASME code-compliant work without referring to the original unprocessed image.

It would be useful for the radiographic image processing community to start to formalize and standardize the requirements and methods for image processing. Especially useful would be organizing round-robins using several standardized digital images (e.g., images of welds and castings) for comparing capabilities of currently available image processing programs and for evaluating new image processing algorithms. Quantization of the capabilities of the image processing algorithms is needed in two areas: (i) evaluation of the minimum observable flaw (or IQI feature) in enhanced images, and (ii) evaluation of artifacts introduced by the image enhancement method.

REFERENCES

1. ASME Boiler and Pressure Vessel Code, Section V "Nondestructive Examination", Article 2 "Radiographic Examination", Mandatory Appendix IV "Interpretation, Evaluation, and Disposition of Radiographic and Radioscopic Examination Test Results Produced by the Digital Image Acquisition and Display Process", 2010 edition.