Integrating quality control tests in a computed tomography system

Lucía FRANCO 1, Pablo G. TAHOCES2

1 Technological Center AIMEN, O Porriño, Spain
Phone: +34 986 344000, e-mail: lfranco@aimen.es
2 CITIUS, Campus Sur, Santiago de Compostela, Spain; e-mail: pablo.tahoces@usc.es

Abstract
Quality control (QC) is of primary importance for computed tomography systems to obtain reliable data for Non Destructive Testing (NDT). A QC protocol is pursued for the AIMEN dual detector CT by a software add-on update on the reconstruction and visualization software.

Image quality parameters are considered following standards and other published papers: uniformity, noise, SNR, contrast, pixel size and spatial resolution. Geometrical values have also to be considered for the adjustments of the CT system, for the scale calibration and geometrical alignment corrections. A simple initial image calibration is proposed for the offset correction for further reconstruction.

The aim of this protocol is to simplify the quality tests to be performed periodically in an inspection environment by an end-user. This is achieved by minimizing the number of image tests along with their integration in a unique software tool for reconstruction and visualization. It is also transferable to other CT systems and for digital detectors focused only on digital radiography.

Keywords: Computed tomography, cone beam CT, visualization software, image quality

1. Introduction

Quality control (QC) tests for industrial computed tomography (CT) systems are well established by industry standards (as seen in [1-4]). Nevertheless, the implementation of such tests in an industrial system for a daily routine is not straightforward: common implementations cover general phantoms or more detailed elements for specific applications. As examples, general methods for digital detectors translated to CT quality applications, mechanized probes for metrology applications, or specific specimens with faults for composite inspection can be found in bibliography [5-7].

A simple approximation for a QC protocol for general systems is pursued in the present paper. It has been developed and implemented for the AIMEN dual detector CT (based on fan beam and cone beam configurations) but it can also be adapted to other integrated-elements CT, commercial systems or even for digital detectors based on digital radiography.

This protocol has been implemented as a new software add-on in the current software solution covering reconstruction along with visualization [8]. From an initial configuration of image quality parameters, data calculation can be directly solved within the software graphical user interface along with geometrical alignment data for further reconstruction.

Quality image parameters that are considered in this article are: uniformity, noise, SNR, contrast, pixel size and spatial resolution. We propose a complete characterization for these parameters that can be accomplished from simple phantoms for general CT inspection purposes.

2. Method and materials

The considered image parameters can be implemented in a general quality assurance protocol establishing a first characterization as "initial state of the system". The developed protocol for quality control in the considered CT facility must establish the test periodicity, phantoms and system parameters. For example:
• System parameters: acquisition energy, number of projections.
• Phantoms: test cylinder, metallic thin wire, duplex wire IQI phantom (following [9]).
• Materials of interest: aluminium, steel, polymethyl methacrylate (PMMA). Aluminium and steel account for the most common materials in NDT applications, and PMMA can stand for low attenuation materials (as composites).

Figure 1: 3D surface rendering of an Al cylinder with a metallic wire stuck to it, as acquired for QC tests.

2.1. Image parameters

The proposed image quality parameters are calculated from the reconstructed tomographic images of the chosen cylinder or the thin wire/duplex wire slices. The definitions for the parameters are described below, based on the Standard Guide for Computed Tomography (CT) Imaging [2]:

2.1.1. Image quality parameters

1) Uniformity. The uniformity is calculated from 5 different regions of interest (ROI) in the cylinder phantom image (see Figure 2). The uniformity value is established as the mean value (in units of cm⁻¹, linear attenuation coefficients) for every ROI divided by the mean value of an extended area covering the phantom image, as a dimensionless number. The maximum of these values will be computed as the final uniformity value.

2) Noise. The noise measurement is calculated as the standard deviation of the CT values of a ROI selected by the cursor over the image. An ensemble of adjacent non-overlapping ROIs is taken from the marked ROI in the cylinder image (Figure 2), where the standard deviation is calculated over each ROI and the mean value of this set of standard deviations is taken as the final value for noise.
3) **SNR (Signal to Noise Ratio).** The signal to noise ratio is calculated as the ratio of the mean value and noise (as the standard deviation) of a given homogeneous region, selected by the cursor within the test object in the reconstructed image.

4) **Contrast.** The contrast value for a system can be defined as the relative difference between two different regions in the image, expressed as a percentage value. In order to establish a concrete value in a quality control process, the contrast between the background and the object in the cylinder image is calculated. The characteristic values for background and object are obtained as the mean value of the CT numbers of two ROIs selected by the cursor within the background and the cylinder. Mathematically:

\[
\Delta \mu (\%) = \frac{\mu_c - \mu_b}{\mu_b} \times 100
\]

where \( \mu_c \) is the measured cylinder mean value and \( \mu_b \) is the background measured mean value.

5) **Spatial Resolution.** Detectability alone (for example, by visualizing a thin wire) is often not sufficient for image quality characterization of the system, since close features must be detected and also resolved. The spatial resolution characterizes the ability of a system to distinctly depict two objects as they become smaller and closer together. A duplex wire IQI is imaged to control the spatial resolution in lp/mm. Considering [9], each pair of lines are associated to values of: 10, 7.9, 6.25, 5, 3.85, 3.125, 2.5, 2, 1.56, 1.25, 1, 0.79, 0.625 lp/mm for elements 13D, 12D, 11D, 10D, 9D, 8D, 7D, 6D, 5D, 4D, 3D, 2D, 1D.

The duplex wire IQI is analyzed by using the corresponding surface mesh plot (Figure 3):
6) MTF (Modulation Transfer Function). The MTF is defined as the ratio of the output modulation and the input modulation and it is related with the spatial resolution of the system. There are several methods to obtain the MTF, and in our case we have chosen the one based in the magnitude of the Fourier transform of the PSF (Point Spread Function). Even though ideal point objects do not exist in the real world, the PSF can be approximated by the reconstructed image of a thin wire. The MTF is calculated over the 360 degree range and averaged to finally obtain a single MTF curve.

An open graph has been implemented for the MTF calculation, since different values can be considered for quantifying the spatial frequency from the MTF: 50%, 20% or even 10%. 

2.1.2. Geometrical values

1) **Pixel size**. Pixel size is usually part of the header of the different image formats employed to store a CT image. In those cases where image standard formats are employed (as tiff files, for example), the information related to pixels dimensions is not preserved by default within the header. In order to retrieve such information, a procedure has been developed to calculate the pixel size directly from the image. The value obtained is stored in an xml file and it can be retrieved for further calculations.

2) **Magnification - SOD fit.** For CT systems with variable magnification, it is useful to obtain a characterization for the magnification (calculated from the pixel size) depending on the Source to Object Distance (SOD). This characterization can be established through a linear fit between the inverse value of the magnification with the SOD value:

\[ M^{-1} = a \, \text{SOD} + b \]  

(1)

with \( a, b \) the linear coefficients fitted for the CT system.

3) **Image offset for reconstruction.** Ideally, every element of the CT system must be perfectly aligned, specially the source focus - center of rotation - center of the detector, in order to obtain reliable reconstructed slices. The use of different magnifications may derive in time appearing displacements (an offset value from the center axis) that will affect this alignment. Our visualization software (as some software solutions) includes an entry for correcting this offset in the process of reconstruction. This value is used to displace the center of the detector until the correct reconstruction is reached.

In order to avoid time-consuming within the reconstruction process, a method for automatically fixing the offset value is proposed involving the thin wire image. The thin wire is rotated and its corresponding sinogram - data before CT reconstruction - is analyzed. The sinogram center (seen as a sine profile) must be at the centre of the detector, and the corresponding displacement (centre pixel - sinogram centre) will be the desired offset value.

![Figure 5](image)

**Figure 5:** Automatic determination of the offset by means of the sinogram of a thin wire. Small deviations in the alignment can cause distortions for the CT reconstruction.
2.2. Software implementation

The visualization platform of the CT system has been developed for NDT applications based on 2D and 3D images [8]. The platform allows reading proprietary formats that are designed for capturing sinograms and projection images from both conventional computed tomography and cone-beam tomography, along with the main related CT formats. The corresponding reconstruction algorithms have been encoded (filtered back-projection for conventional CT and Feldkamp-David-Kress for cone-beam CT).

The visualization application allows to analyze digital radiography and tomography (pre- and post-reconstruction) for different detectors. Two solutions are implemented for 3D rendering: one using an opacity function and a second based on an isosurface of the volume. All the code was written in ANSI C++ and cross-platforms libraries like Qt (Nokia Corporation) and VTK (Kitware Inc.) that provides the necessary functionality to implement both the user interface and the 3D rendering.

This framework establishes a common structure for the development of new applications as the specific tools for calculating image quality parameters. The different parameters calculations were directly implemented as a plug-in in the software, and they are accessible from the graphical user interface (see Figure 6).

![Figure 6: Example of the graphical user interface for calculating image quality parameters.](image)

2.3. Data collection and results

The working flow for the final quality control tests can be thought as a simple routine in an ND inspection environment. First of all, the QA-dedicated phantoms (cylinder and wire/duplex wire IQI) must be imaged following the established parameters for the facility's protocol. The software will be used to reconstruct the calibration data. Current reconstructed output data in our system is in Analyze SPM format (from www.mayo.edu); the reconstruction data can be general for the complete phantom or for chosen slices, which will accelerate the data processing time.

Once finished, the software Quality Check Tab (within the principal Reconstruction Tab) will allow to choose the relevant parameter and to perform the different required tests. In each case the software will require the base image along with one of three different buttons for different parameters, namely: regular ROI, irregular ROI and linear measurement.
Pop-up windows will show the required interactions from the user, providing both the instructions and the calculated data after finishing the process.

2.3.1. Pixel size definition and implementation

Previously to the quality control test, the pixel size must be established since it is needed for spatial resolution data. Pixel size can be considered from different approximations. In first place, the proprietary format of our dual CT system includes a data header covering acquisition information where the pixel size was obtained from an initial calibration of the variable magnification data. For other systems with standard initial data (as tiff images), pixel size calibration is implemented within the software as explained in the 2.1.2. section.

![Figure 7](image-url): Consecutive stages for pixel size calibration: test and real size data (left) and point determination with generated xml file (right).

2.3.2. Summary of the quality control parameters

The calculation of the quality control parameters (implemented in the visualization software) together with the required steps from the user and the results are summarized in Table 1:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Base image</th>
<th>Steps</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uniformity</td>
<td>Cylinder phantom</td>
<td>Mark regular ROI</td>
<td>Uniformity value (dimensionless)</td>
</tr>
<tr>
<td>Noise</td>
<td>Cylinder phantom</td>
<td>Mark regular square ROI</td>
<td>Noise value (dimensionless)</td>
</tr>
<tr>
<td>SNR</td>
<td>Cylinder phantom</td>
<td>Mark regular ROI</td>
<td>SNR value (dimensionless)</td>
</tr>
<tr>
<td>Contrast</td>
<td>Cylinder phantom</td>
<td>Mark background point and object point</td>
<td>Contrast value (percentage)</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>Duplex IQI image</td>
<td>Mark slice area</td>
<td>Line pair detectability</td>
</tr>
<tr>
<td>Pixel size</td>
<td>Cylinder phantom</td>
<td>Mark extreme points</td>
<td>xml file</td>
</tr>
<tr>
<td>MTF</td>
<td>Wire image</td>
<td>Mark center point</td>
<td>MTF plot (Figure 4)</td>
</tr>
</tbody>
</table>
4. Conclusions and future work

In conclusion, the calculation of the different image quality parameters were therefore included in the visualization software to successfully complete a QC protocol for the dual geometry CT system. In this way, a set-up of acquisition parameters can be chosen for an initial characterization and a periodicity for the CT quality protocol can be established, both for the FB and CBCT configuration, as in the following scheme [10]:

Table 2: Example of parameters and periodicity for QC tests in computed tomography.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Material</th>
<th>Projections</th>
<th>Periodicity</th>
<th>Energy (keV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uniformity</td>
<td>Fe/Al/PMMA cylinder</td>
<td>900 - FB</td>
<td>Monthly</td>
<td>225 - Fe / Al</td>
</tr>
<tr>
<td>Noise</td>
<td>Duplex wire IQI</td>
<td>720 - CBCT</td>
<td>Monthly</td>
<td>150 - PMMA</td>
</tr>
<tr>
<td>SNR</td>
<td>Thin wire</td>
<td></td>
<td>Monthly</td>
<td></td>
</tr>
<tr>
<td>Contrast</td>
<td></td>
<td></td>
<td>6 months</td>
<td></td>
</tr>
<tr>
<td>Spatial resolution</td>
<td></td>
<td></td>
<td>6 months</td>
<td></td>
</tr>
<tr>
<td>Offset measurement</td>
<td></td>
<td></td>
<td>6 months</td>
<td></td>
</tr>
</tbody>
</table>

Since these tests can be performed in a single acquisition while operating with the same software tool for reconstruction, they can be implemented periodically in an inspection environment by and end-user operator. A data set can be then completed within time to study the image performance derivation of the system, or even to extend the periodicity of some tests whereas its evolution is not significant.

This software implementation is an easy solution for streamline quality control tests in CT and it is directly transferable to other CT systems or even as simple tests in radiography, covering the digital detectors image performance.

References
