User Manual

This is the user manual for the AutoPIA software. Is divided into three parts.

The first is a brief overview of the software with a description of its main features and benefits.

The second has a goal-oriented structure, therefore sections correspond to the main goals that a user would like to perform with the software.

The third describes how the software calculates all the Image Quality Indices (IQI).

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Overview

Description

AutoPIA (**Auto**matic **P**hantom **I**mage **A**nalysis) is a software for automatic recognition and analysis of test images of objects (phantoms) used to evaluate image quality. AutoPIA is able to quickly provide reproducible and objective quality indices for routine quality control processes aimed at optimizing the performance of an X-ray system.

AutoPIA automatically analyses a given digital image and quickly calculates objective, reliable, and reproducible indices to evaluate the performance of a radiological equipment. Then it stores the analysis results and provides control charts with baseline and threshold values in order to keep track of quality trends and abnormal conditions.

Benefits

Before the advent of digital era in diagnostic imaging, routine quality controls were carried out by human observers that evaluated image quality by counting visible details and measuring optical density. The process was inevitably slow, affected by subjective criteria and variable over time, resulting in unreliable assessments with high costs.

With digital images, the process of analysis and evaluation can be automated, carrying along certain advantages:

- **economy**: the computer is much faster and costs less than any human, manual analysis for complex phantoms takes about 20 minutes, if multiplied by the number of tests to be carried out for routine controls and the number of devices to control, the amount of work inevitably grows;
- **efficiency**: an analysis performed by the computer is more sensitive and accurate; AutoPIA is able to calculate quality indices much more information-rich rather than the simple count of visible details, and this allows to highlight in advance situations where the performance of the equipment is slightly degrading, without having to wait for one or two details to become invisible;
- **objectivity**: the analysis is not influenced by human choices; AutoPIA is completely independent; once the image has been selected and the phantom used has been specified, the analysis is fully automatic and ends with the measurement of quality indices, and evidence of which have exceeded the defined thresholds; furthermore, the indices can be inserted into the control charts to identify trends;
- **reproducibility**: the same image will be evaluated in the same way, regardless

of the person performing the analysis and her/his competence or experience.

AutoPIA methods and algorithms are based on advanced knowledge of medical physics and computer science, and this provides:

- **incontestable results**: the quality indices used by AutoPIA have a solid scientific basis and were validated using appropriate methods;
- **transparency**: AutoPIA declares the algorithms used to calculate the quality indices and lets check for every image and every detail, what are the areas used by the algorithms; no magic number, everything is documented directly on the image used;
- **ease**: AutoPIA is very easy to use because it is completely automatic and conforms to the most common interfaces used for computer programs; it hides the complexity of analysis algorithms including artificial intelligence algorithms and advanced techniques of optimization;
- **compatibility**: AutoPIA calculates the indices used by the manual analysis of images, allowing easy integration with the processes of quality control currently implemented;
- **reporting**: for each quality index, AutoPIA generates a control chart that highlights the trends, with the possibility of establishing benchmarks that generate alarms if exceeded. In the case of scientific or statistical work of greater complexity, AutoPIA export analysis results into a format compatible with popular spreadsheets (MS Excel, OpenOffice Calc), therefore allowing the use of analysis results in complete autonomy.

Supported phantoms

AutoPIA is currently able to recognize and analyze the following phantoms of Leeds Test Objects:

- Mammography
  - TOR MAS
  - TOR MAX
  - TOR MAM
  - DMAM2
  - DMAM2 Gold
  - PIX MAM 300x240
  - PIX MAM 250D
  - Uniformity (EUREF 4th ed. 2b.2.2.3.1, 2b.2.2.3.3, 2b.2.2.3.1 from supplement)

- Radiography (CR and DR)
  - TOR CDR
  - PIX 13
- Fluoroscopy
  - TOR 18FG
- Contrast threshold
  - TO 20/16
  - TO 12/10
- Dental
  - CBCT 161

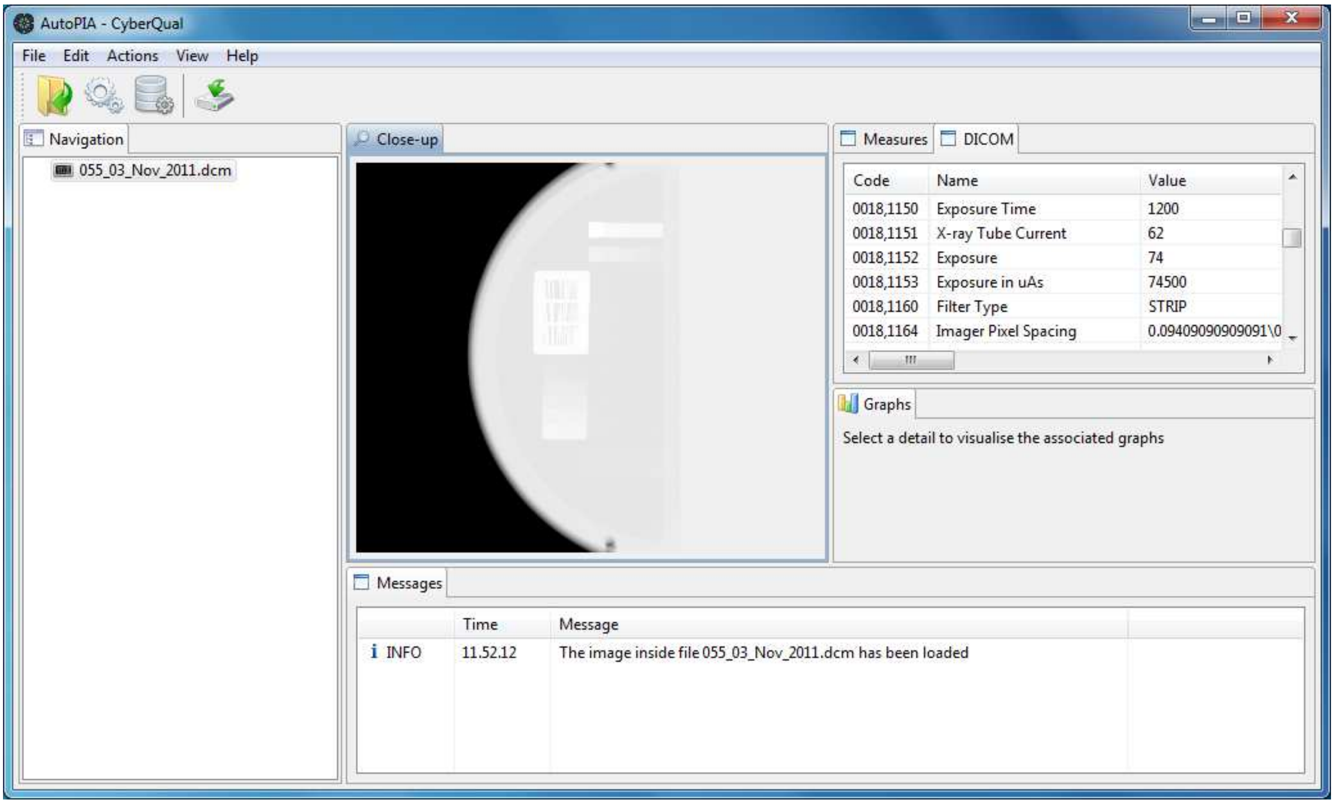
Goals

Open a file

Open a file is a very basic operation that is performed, like in the vast majority of desktop applications, with the menu File|Open. As an alternative, it is possible to use the toolbar open button.

AutoPIA supports the following file formats TIFF, GIF, JPEG, PNG, DICOM, BMP, PGM and FITS. DICOM is the preferred one, because it has been specifically designed for medical images and because it contains lot of useful information about the image itself and the acquisition process (e.g. exposure conditions).

When the image is loaded, it is visualized inside the Close-up view, and if the image is a DICOM one, all DICOM headers are visualised in the DICOM tab on the right.

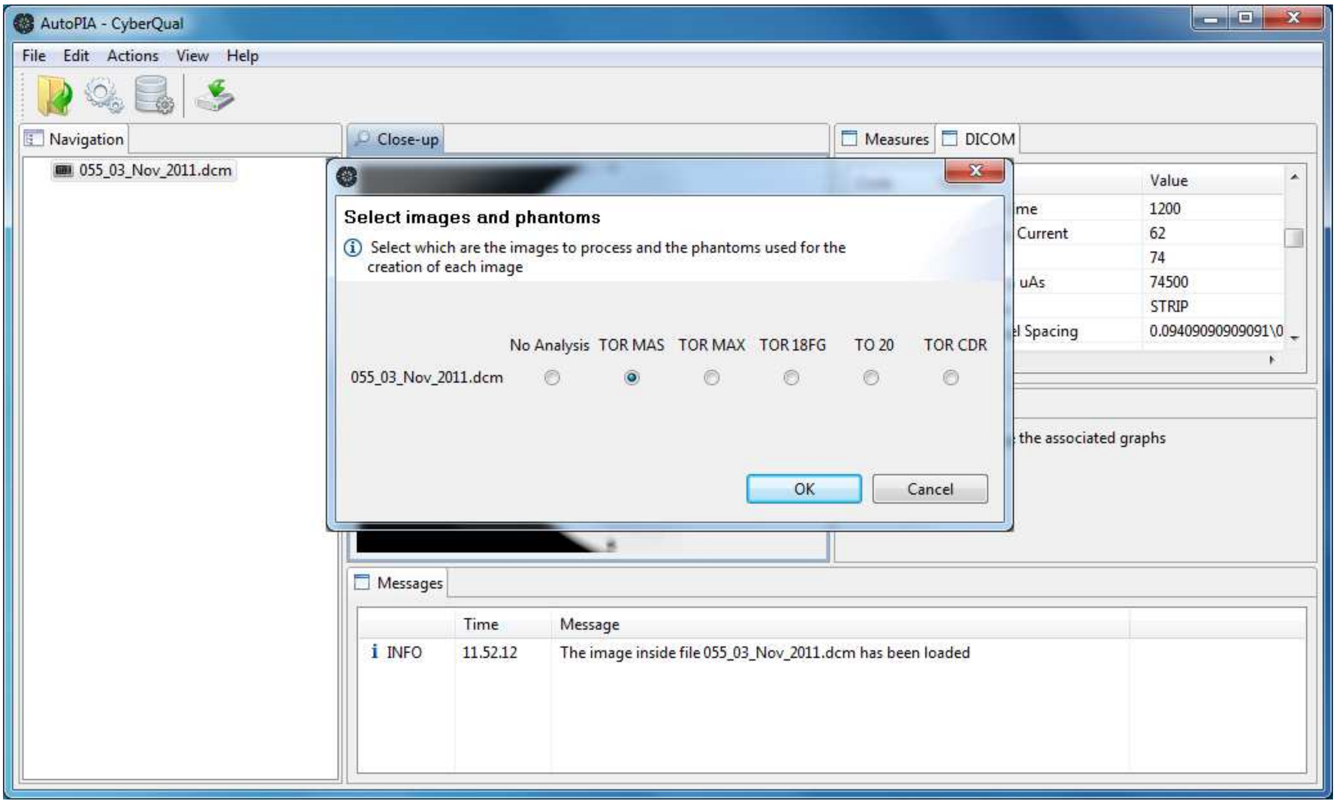


Analyse the image

The image analysis is automatic and the only action requested to the user is the selection of the phantom type.

In order to start the the analysis it is possible to use the menu Actions | Analyse or click on the analyse button on the toolbar.

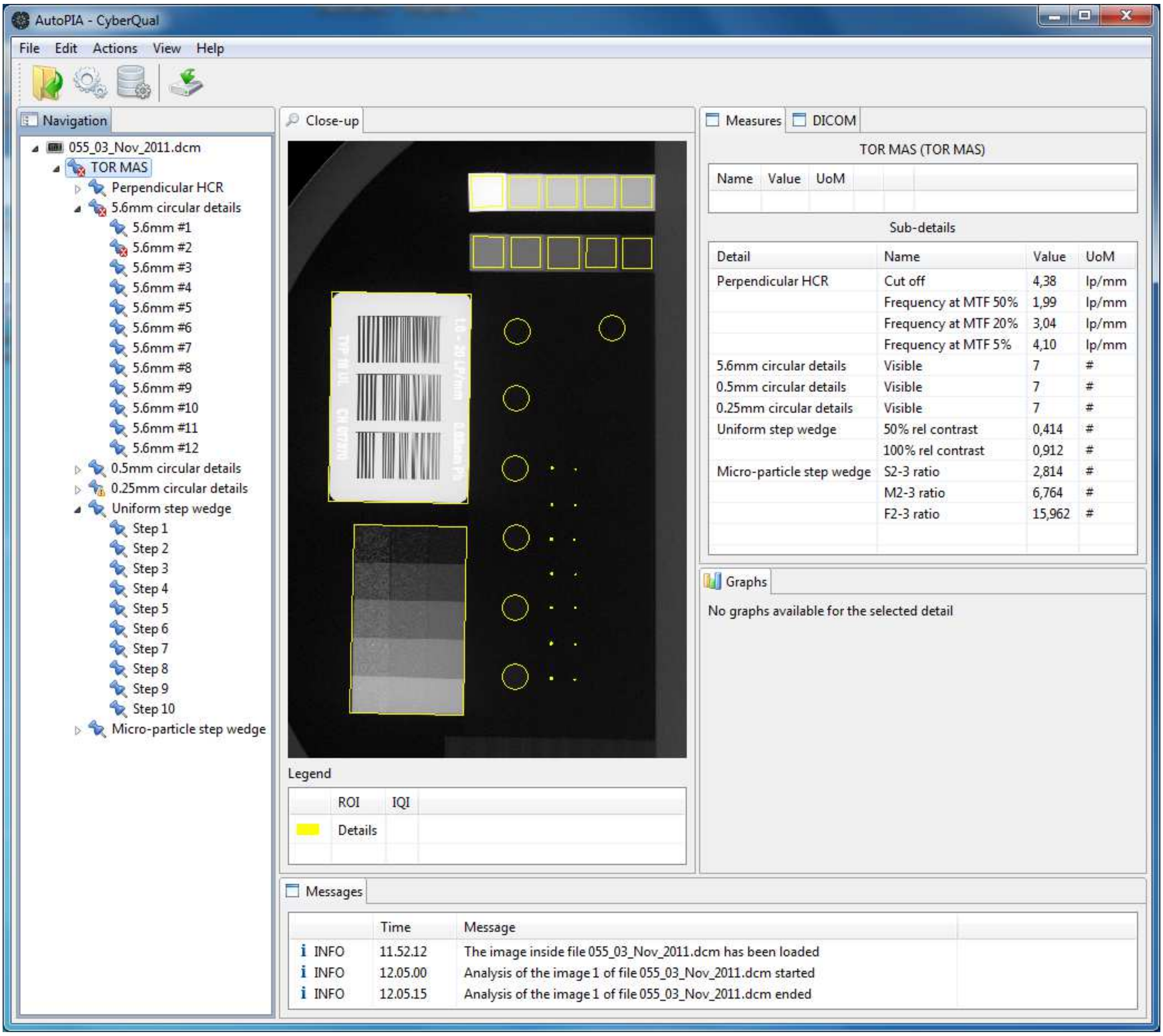
If it is possible to select among different phantoms, the following dialog appears.



This allows the user to select which is the phantom that generates the image. If the license allows only one phantom, this window will not appear and AutoPIA will assume that the image has been generated with the phantom.

Select the right phantom and click on Ok. AutoPIA will start the image analysis while showing a progress bar. Just under the progress bar there is a Cancel button that can be used to interrupt the analysis. The analysis lasts for a while depending on the image features. Normally it never lasts more than 1 minute, but in certain circumstances it could last something more (seldom it reaches two minutes).

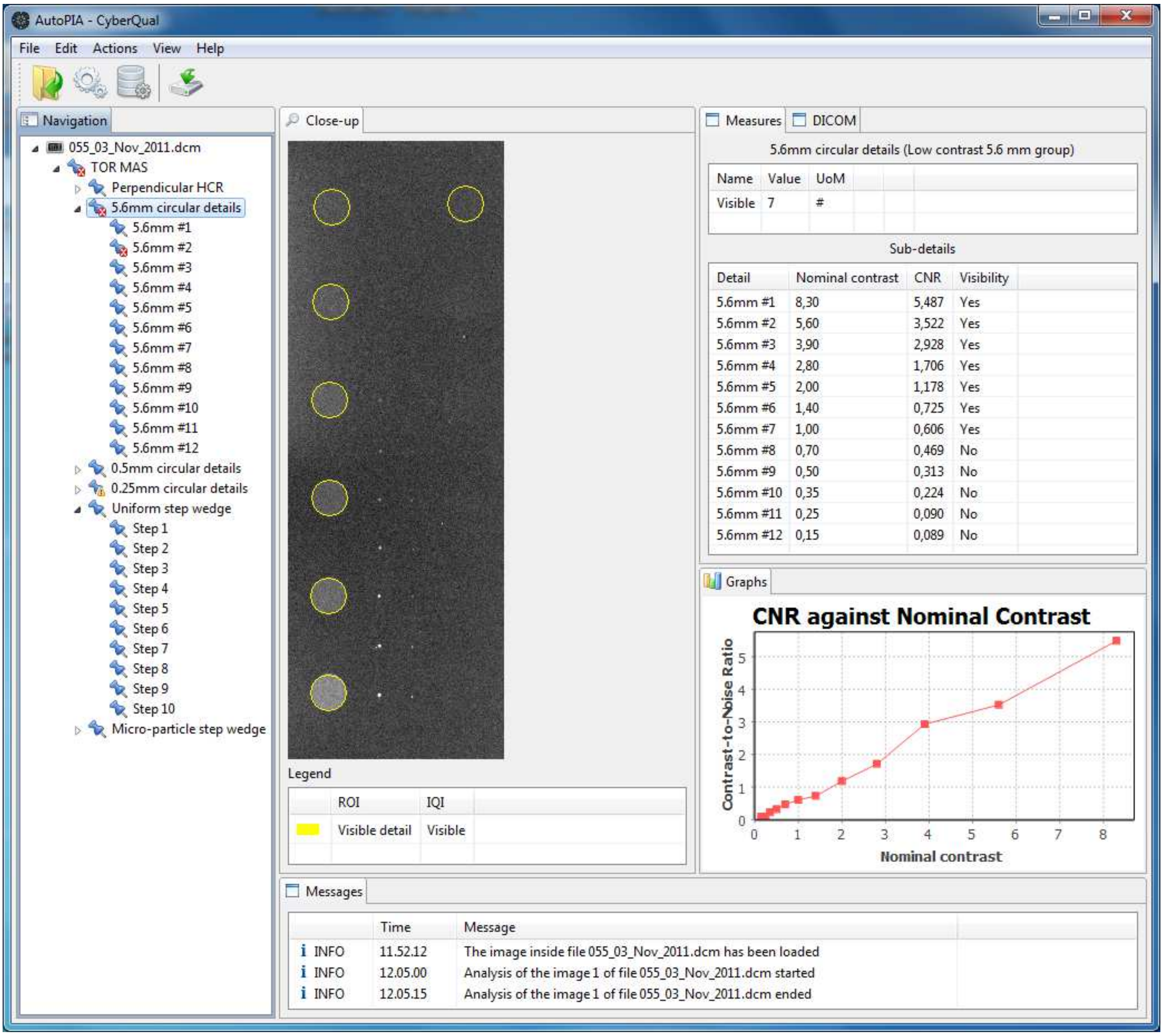
When the analysis is completed, the results are presented.



The result of the analysis contains lot of information, especially for phantoms containing lot of details. In order to allow an easy and efficient navigation through results, they are structured in hierarchical fashion, which is represented on the left, inside the view called navigation. Every node of the tree corresponds to a detail (or collection of details) and when selected, its features are shown in the other views of the working area:

- the region of the image containing the detail is shown in the Close-up view
- the detail image quality indices are listed inside the Measures view: the first table contains the IQIs of the detail, while the second table lists the IQIs of the sub-details (if any)

- if available, graphs are shown in the [Graphs view]



Export results data

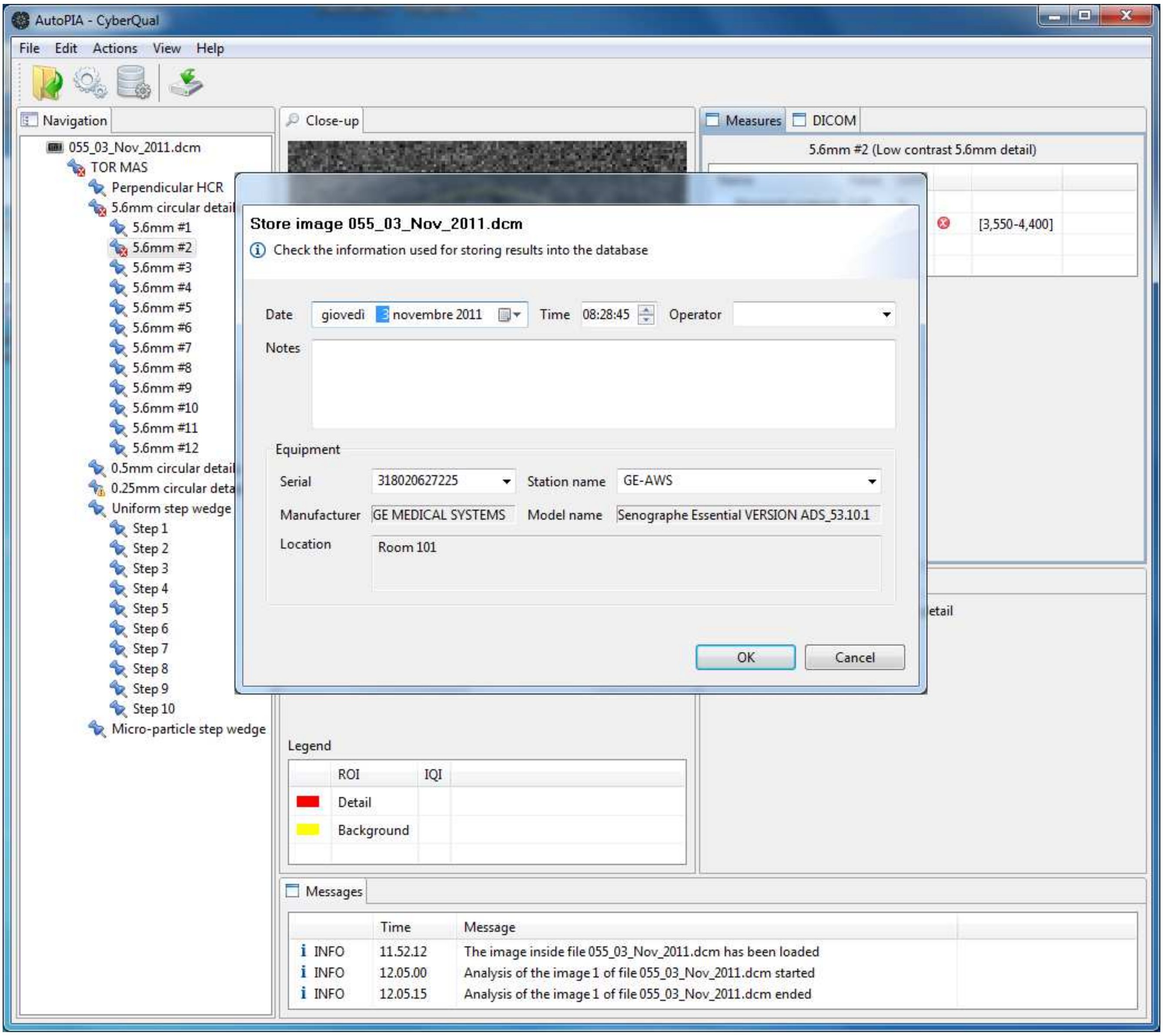
The results of the analysis can be exported in a file with CSV (Comma Separated Values) format. This allows result data manipulation with other tools like spreadsheets or database. This way every user can manipulate the analysis results the way they prefer and with the tools they prefer.

The operation is very simple and can be performed using the menu [File|Export to CSV] or the toolbar export button. A standard Save window appears, like the one used by all standard applications, and the user can select the name of the file and the directory where to save it.

Store analysis data

AutoPIA contains a DBMS (DataBase Management System) in order to store the analysis results. This allows AutoPIA to visualize an IQI (Image Quality Index) over time and thus to give users a clear picture of the IQI trend. Store analysis data into the database is very simple: it is possible to use the menu Actions|Store or the toolbar store button.

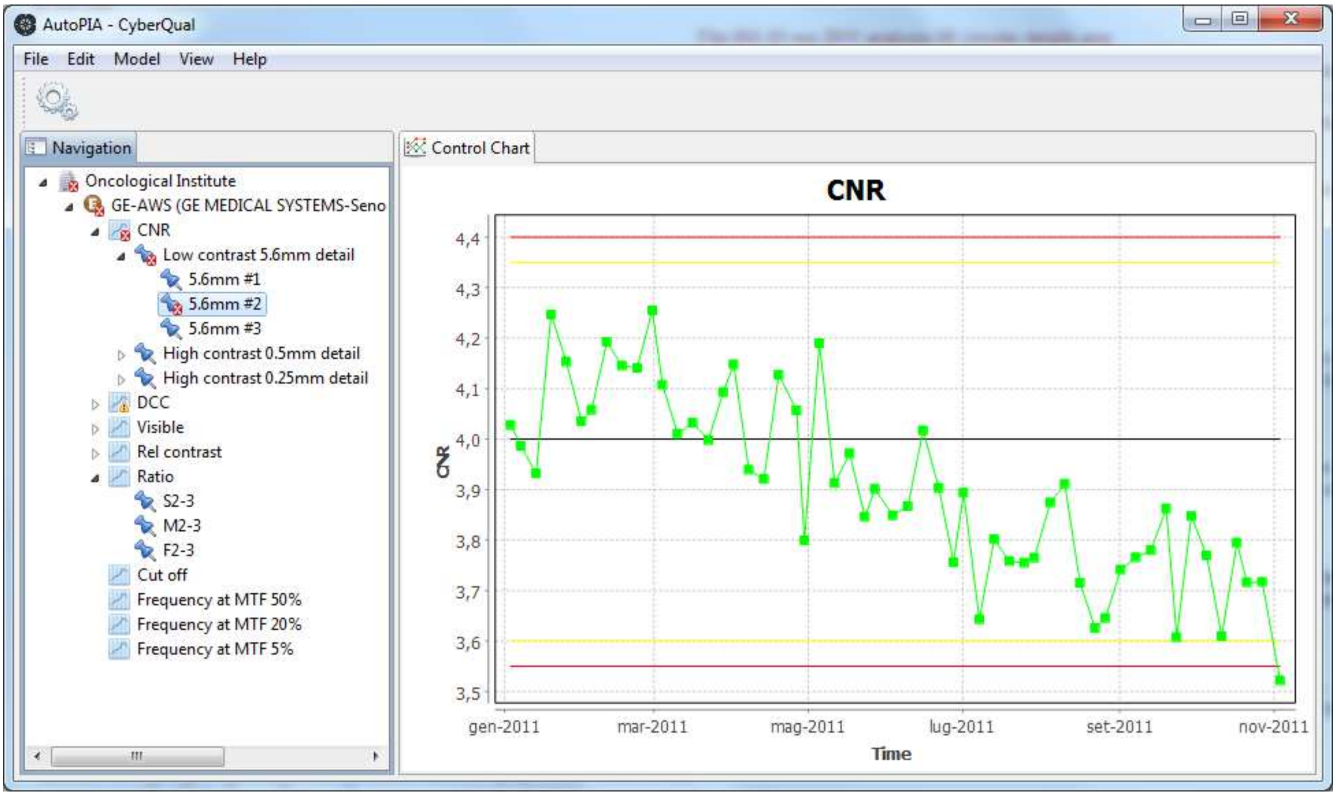
AutoPIA digs inside data associated to the image (like DICOM headers) in order to retrieve all information needed to store the results. For example, the serial number of the equipment under test, the date of the image, the exposure conditions. Sometimes the information is not available and shall be entered manually (for example using the CR modality), sometimes everything is ready and the user is just requested to check data and confirm the operation.



Check control charts

Control charts represent the trend of a statistic inside the range of working values. Control charts are used to visualise the statistic over time and thus to have a clear idea of which are the trends. Furthermore, control charts have also a baseline vale, which is the "normal" value for the statistic and one ore more threshold limiting the working range for the statistic.

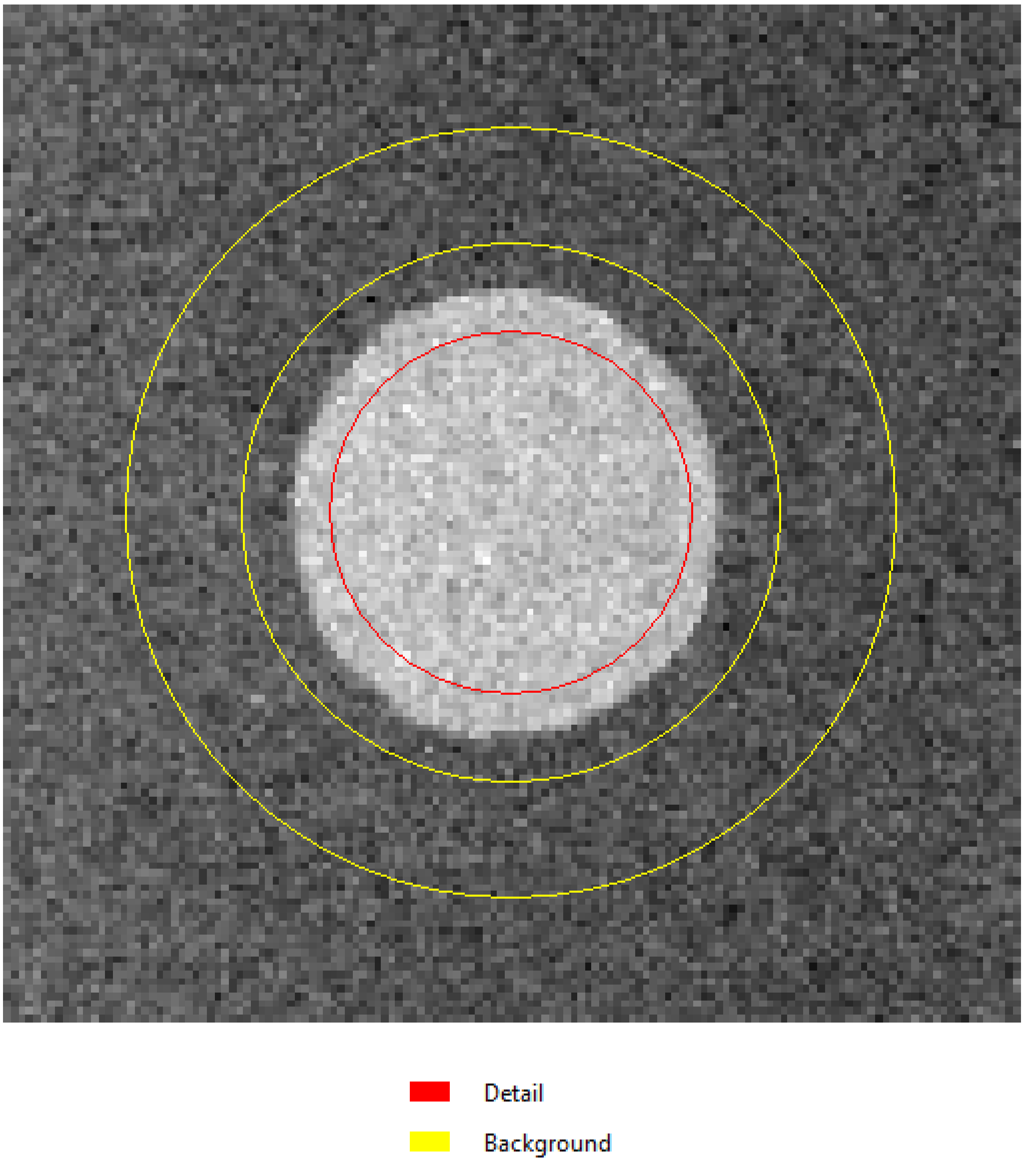
AutoPIA provides control charts for all the IQIs (Image Quality Indices) calculated during the analysis. They are visualized using the menu View|Results layout. The application layout changes completely and appears like this picture.



Every analysis result contains lot of IQIs, so there are lot of control charts that can be visualized. In order to give users a fast access to every control chart, in the Navigation view on the left, there is a tree for navigate through control charts. Hierarchy starts with the medical centres, then there are all the equipments inside the medical centre, then the test objects used for the equipment (if more than one) and then the detail hierarchy inside the test object. This structure is the same one used for the analysis. Every node representing a detail for which an IQI has been calculated during analysis, has an associated control chart.

IQIs

Contrast-to-Noise Ratio (CNR)

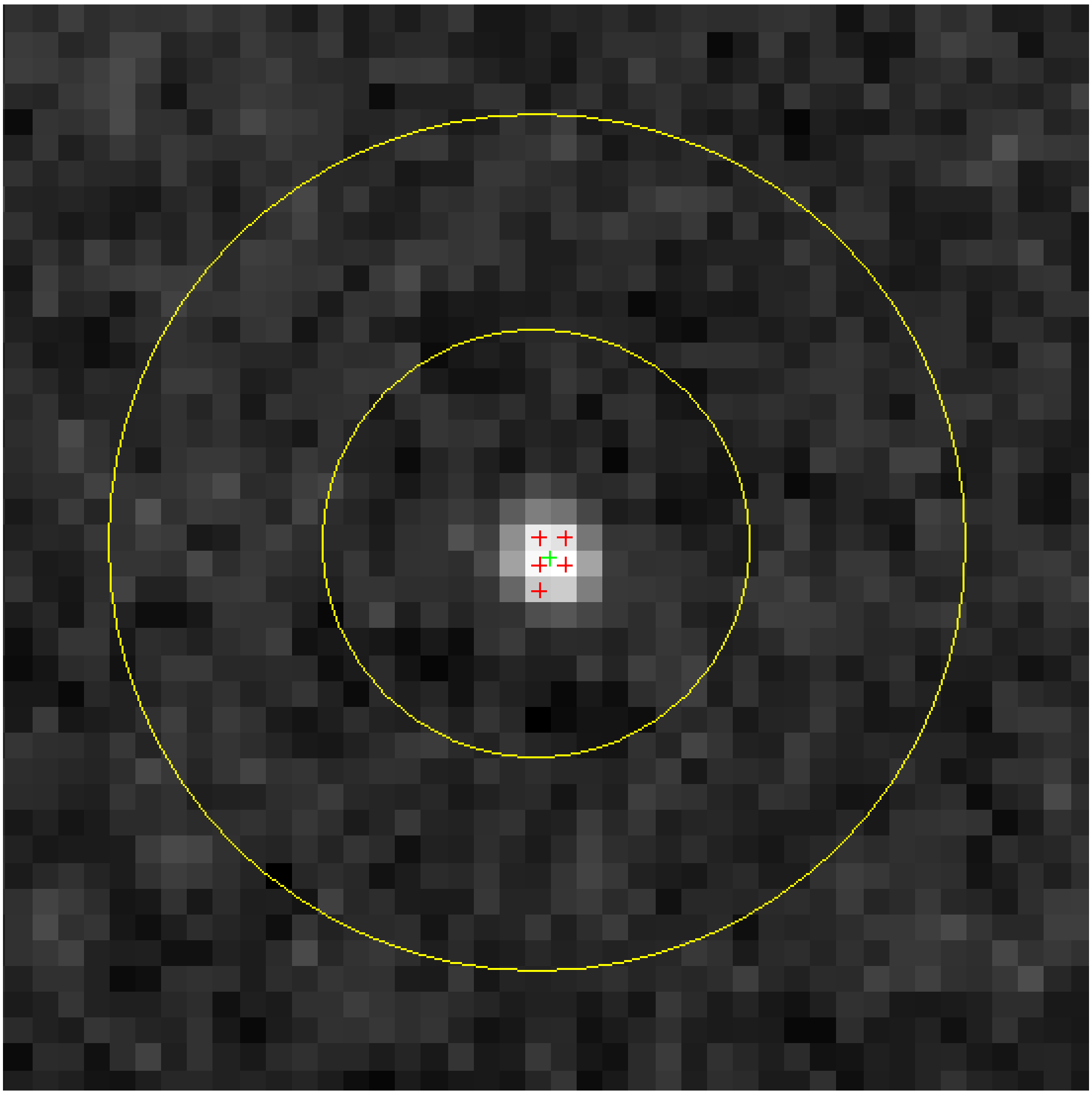


$$CNR = \frac{|\mu_D - \mu_B|}{\sigma_B}$$

where

- μ_D: mean pixel value of the detail ROI
- μ_B: mean pixel value of the background ROI
- σ_B: standard deviation of pixel values of the background ROI

DCC



Detail

Background

Barycentre

$$DCC = \frac{\sum_i PCNR_i \cdot w_i}{\sum_i w_i}$$

where *PCNR* (*Pixel Contrast to Noise Ratio*) is:

$$PCNR_i = |GL_i - \mu_B|, \qquad \forall i \in D_i$$

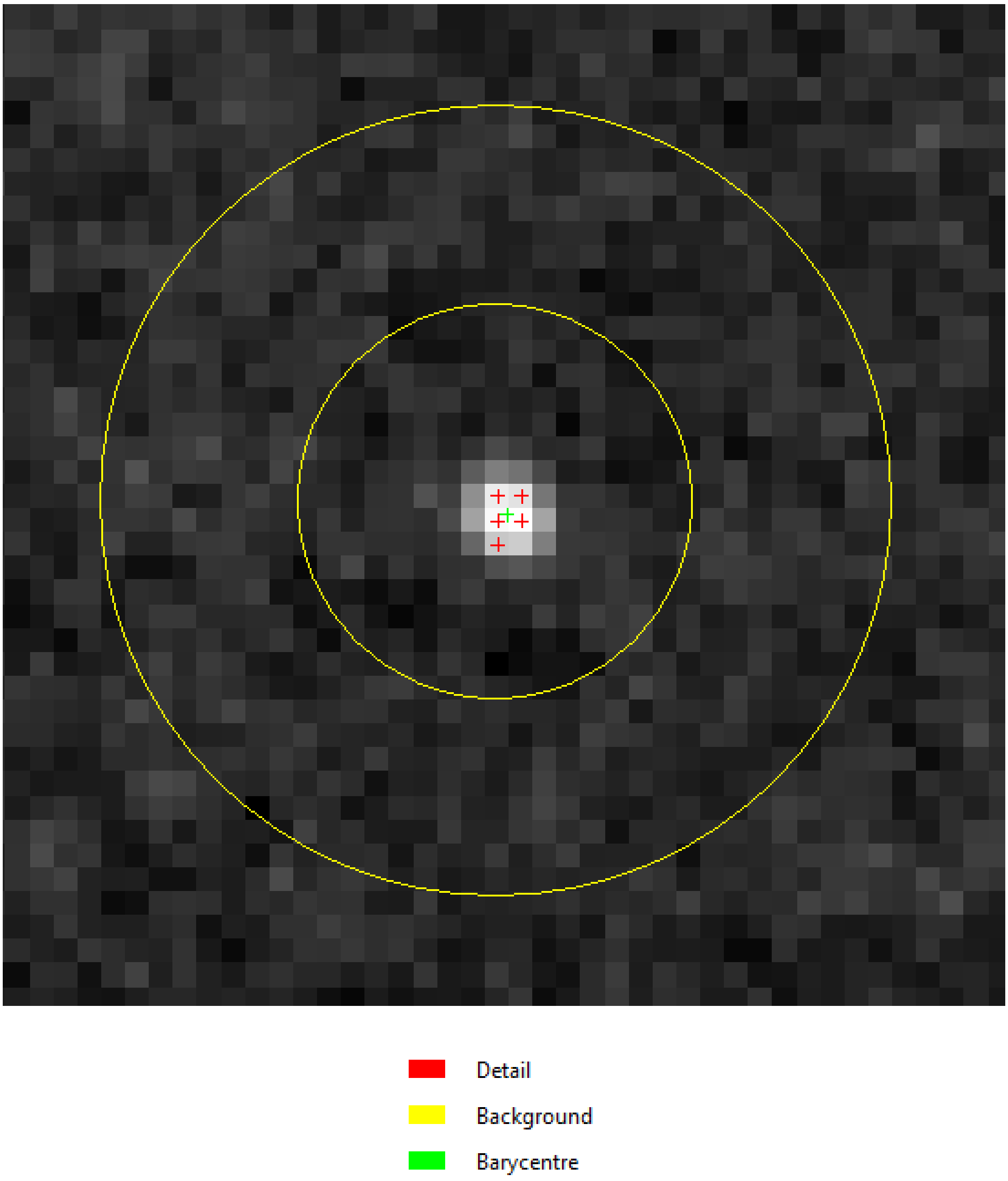
$$D_i = \begin{cases} \{i | GL_i > \mu_B + \sigma_B\}, & \text{if details gray levels are greater than those of back} \\ \{i | GL_i < \mu_B - \sigma_B\}, & \text{if details gray levels are lesser than those of backgr} \end{cases}$$

$w_i = 1$

and

- $\boldsymbol{\mu_B}$: mean pixel value of the background ROI
- $\boldsymbol{\sigma_B}$: standard deviation of pixel values of the background ROI
- $\boldsymbol{GL_i}$ = gray level of pixel i

WDCC



$$DCC = \frac{\sum_i PCNR_i \cdot w_i}{\sum_i w_i}$$

where *PCNR* (*Pixel Contrast to Noise Ratio*) is:

$$PCNR_i = |GL_i - \mu_B|, \qquad \forall i \in D_i$$

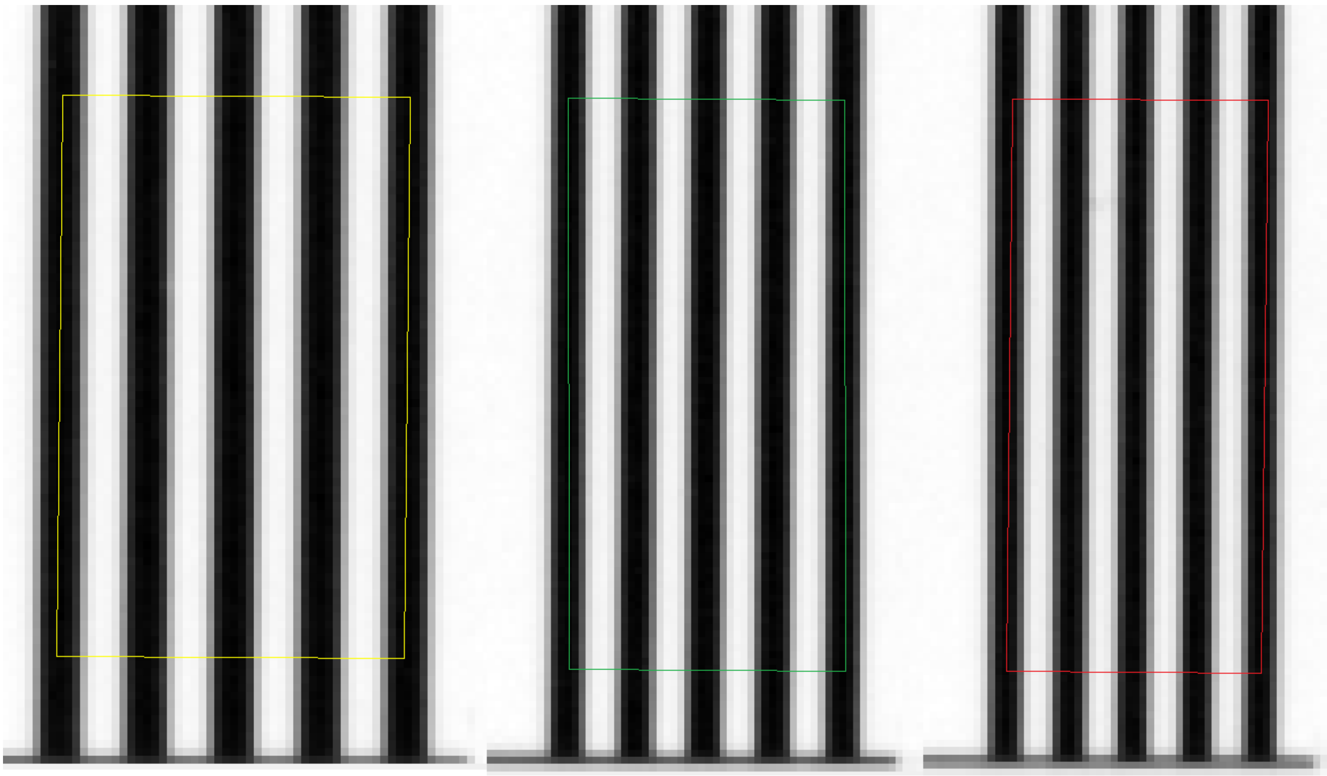
$$D_i = \begin{cases} \{i|GL_i > \mu_B + \sigma_B\}, & \text{if details gray levels are greater than those of back} \\ \{i|GL_i < \mu_B - \sigma_B\}, & \text{if details gray levels are lesser than those of backgr} \end{cases}$$

$$w_i = \begin{cases} \frac{d-2d_i}{d}, & \text{if } d > 2d \\ 0, & \text{if } d < 2d \end{cases}$$

and

- $\boldsymbol{\mu_B}$: mean pixel value of the background ROI
- $\boldsymbol{\sigma_B}$: standard deviation of pixel values of the background ROI
- $\boldsymbol{GL_i}$ = gray level of pixel i

Cut off



Detail 1

Detail 2

Detail 3

Cut off frequency is calculated taken a certain number of regions inside the most defined bar patterns, such that n line pairs are fully included. Taking multiple regions helps confirming the result, but the rational is the same for every region.

The cut off frequency expressed in line pairs over pixels ($[LP/px]$)is

$$f_c\,[LP/px] = \frac{1\,[LP]}{4\,[px]}$$

because 2 pixels (samples) are needed to unambiguously identify the bar and 2 are used for the background, thus 4 to identify a line pair.

Using the idenitfied regions it is possible to calculate the conversion factor r from pixels to millimeters, so to express the cut off frequency in $[LP/mm]$

$$r\,[mm/px] = \frac{l\,[mm]}{l\,[px]} = \frac{\frac{n[LP]}{f[LP/mm]}}{l\,[px]}$$

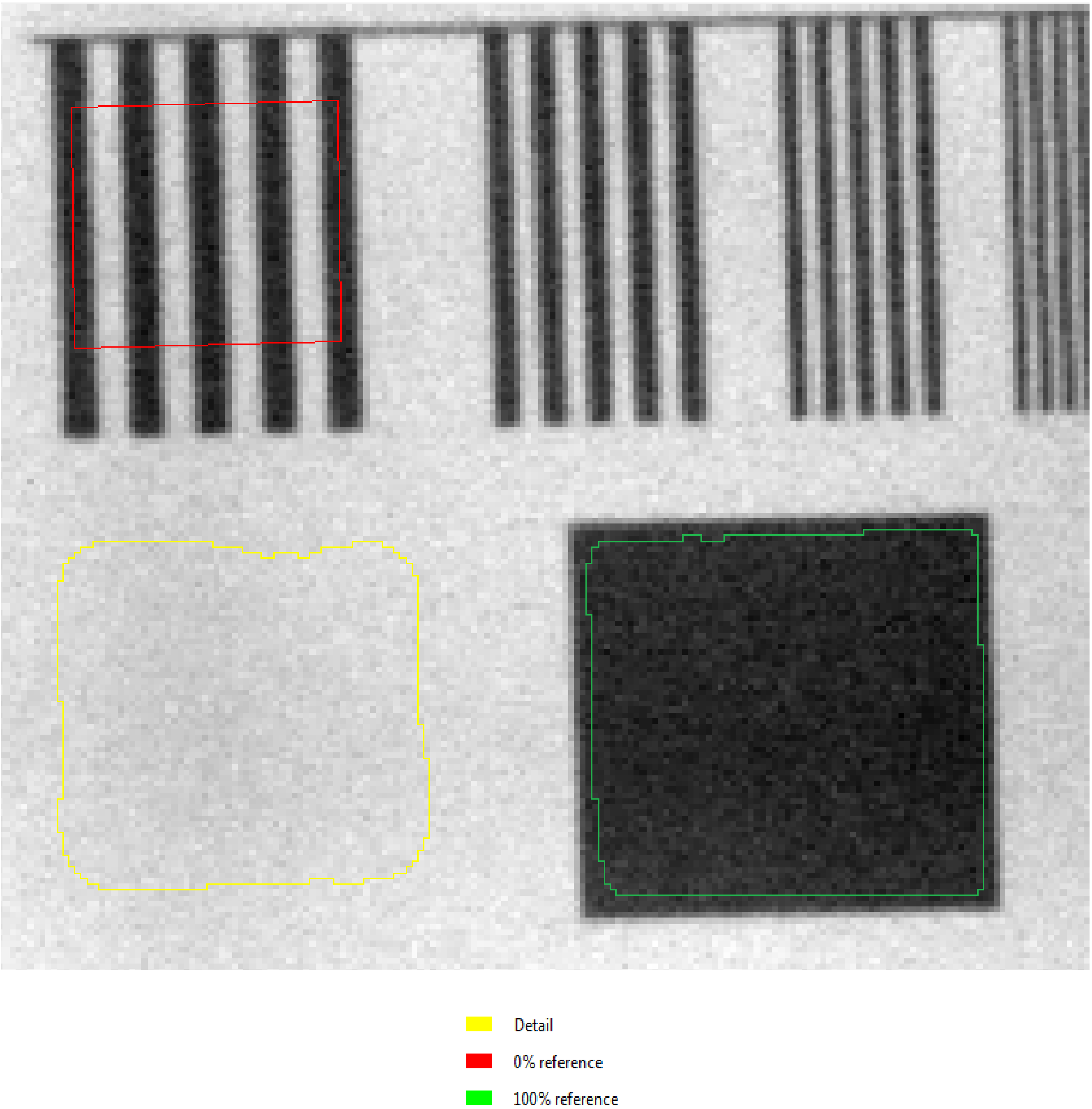
where:

- ***l***: lenght of the bar pattern
- ***f***: is the frequency of the bar pattern
- ***n***: number of line pairs included in the bar pattern

Therefore:

$$f_c\,[LP/mm] = \frac{1\,[LP]}{4\,[px]} = \frac{1\,LP}{4\,[px]\cdot r\,[mm/px]} = 1\,[LP]\cdot\frac{1}{4\,[px]}\cdot\frac{n\,[LP]}{f\,[LP/mm]}\cdot l\,[px]$$

MTF



Modulation Transfer Function (MTF) values are calculated according to **Droege RT, Morin RL.** "*A practical method to measure the MTF of CT scanners*" (Med Phys. 1982 Sep-Oct;9(5):758-60). Authors demonstrate how MTF is related to the standard distribution of pixel values inside a region taken from a bar pattern, with the following relations:

$$MTF(f) = \begin{cases} \frac{\pi\sqrt{2}}{4} \cdot \frac{M(f)}{M_0}, & \text{if } f \geq f_c/3 \\ \frac{\pi\sqrt{2}}{4M_0} \cdot \sqrt{M^2(f) - \frac{M^2(3f)}{9} - \frac{M^2(5f)}{25} - \frac{M^2(7f)}{49}}, & \text{if } f \geq f_c/11 \end{cases}$$

where:

$$M(f) = \sqrt{\sigma_D^2 - N^2}$$

$$M_0 = |\mu_{bar} - \mu_{bkg}| \sqrt{\frac{n_{bar} \cdot n_{bkg}}{(n_{bar} + n_{bkg})}}$$

$$N = \frac{\left(\sigma_{bar}^2 + \sigma_{bkg}^2\right)}{2}$$

and:

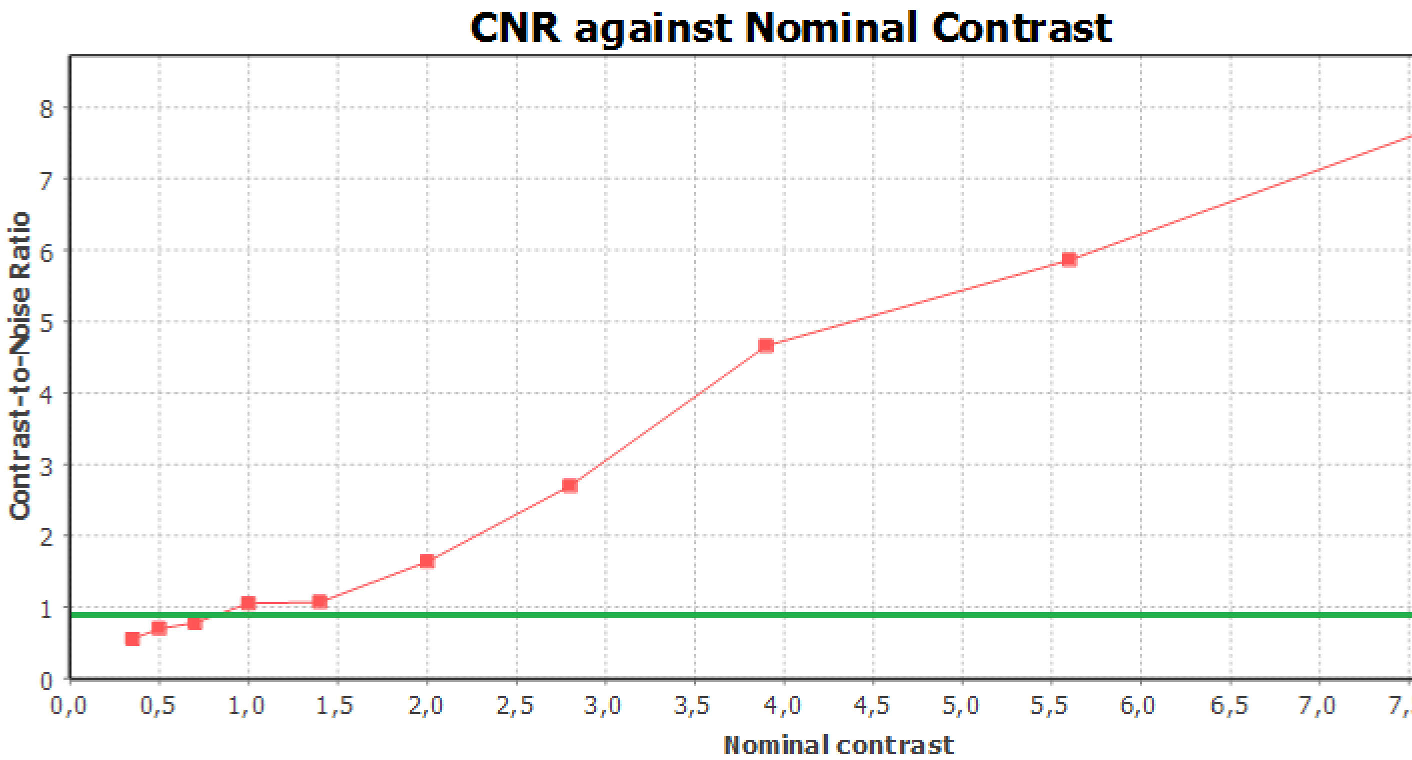
- $\boldsymbol{\sigma_D}$: standard deviation of pixel values inside the bar pattern (detail) region
- $\boldsymbol{\mu_{bar}}$: mean pixel value of the bars reference region
- $\boldsymbol{\mu_{bkg}}$: mean pixel value of the background reference region
- $\boldsymbol{n_{bar}}$: number of pixels of the bars reference region
- $\boldsymbol{n_{bkg}}$: number of pixels of the background reference region
- $\boldsymbol{\sigma_{bar}}$: standard deviation of pixel values inside the bars reference region
- $\boldsymbol{\sigma_{bkg}}$: standard deviation of pixel values inside the background reference region

For frequencies outside the range given by the formulas, a linear interpolation is performed.

Frequency at MTF 50%, 20% and 5%

First the MTF values for all available bar pattern frequencies are calculated. Then, the frequencies at a certain MTF level are calculated with a linear interpolation between the two nearest frequencies having a known MTF value.

Visibility and visible



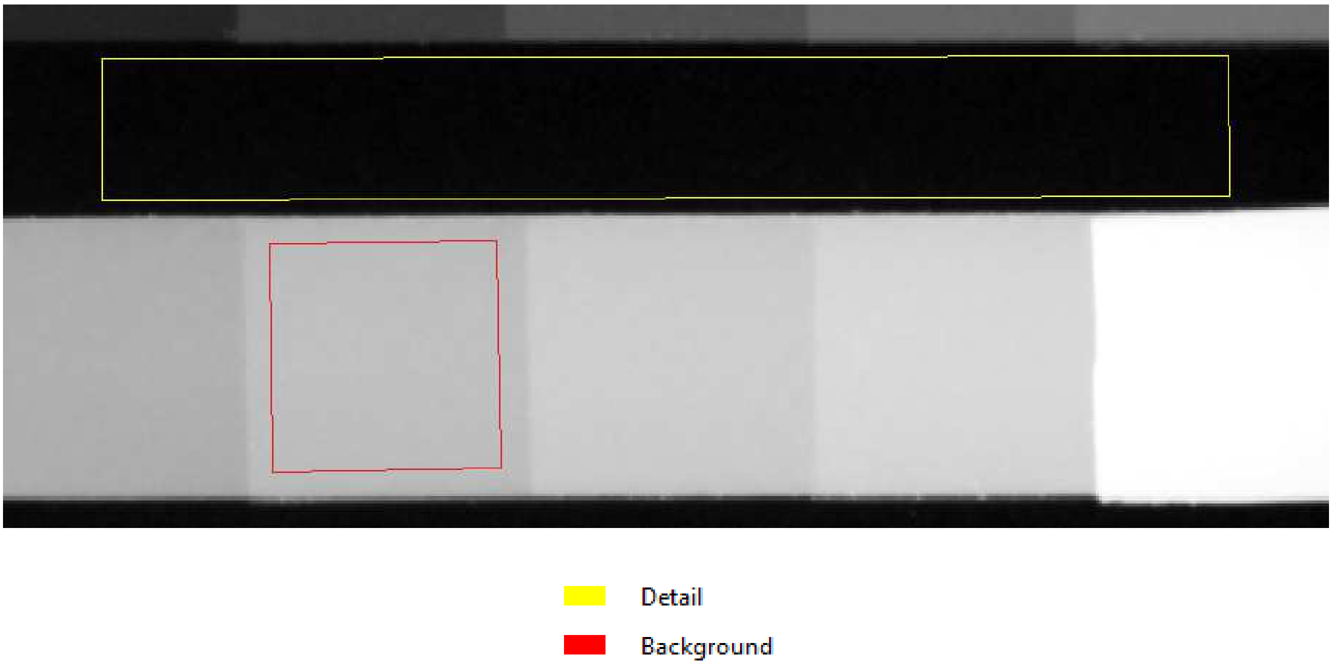
The visibility of details is determined according to the value of an IQI representing the visibility:

- CNR is used for large low contrast details
- DCC is used for small high contrast details

A threshold is set for every group of details and if the value of the IQI is greater thean the threshold, the the detail is considered visible.

Threshold approach is sub-optimal, because the "appropriate" threshold depends on the equipment.

Relative contrast



$$Relative\ contrast = \frac{|\mu_D - \mu_B|}{\mu_B}$$

where:

- μ_D: mean pixel value of the detail region
- μ_B: mean pixel value of the background region

Ratio

Detail

Background

$$Ratio = \frac{\sigma_D^2}{\sigma_B^2}$$

where:

- σ_D^2 : variance of pixel value of the detail region
- σ_B^2 : variance pixel value of the background region

Background region relative to a certain dtail region is selected so to have the same nominal contrast.