

University of Bologna – Department of Physics and Astronomy

**Physics Laboratory Activity: X-ray imaging**

Guide to the lab activity experience and report

The aim of the actual lab activity is to learn how to operate with X-ray imaging detectors as well as with X-ray tubes in order to perform a digital radiography and the comprehension of some of the most important factors and parameters in digital radiography practice. We will study some of the main features that characterize a digital X-ray imaging system: signal to noise ratio, linearity, dynamic range and spatial resolution of a detector as well as the behavior of a polychromatic X-ray beam.

**1. Instrumentation**

Describe the characteristics of the X-ray tube BOSELLO XRG120 (voltage and current range) and the characteristics of the VARIAN PS2520D flat-panel detector (active area size, number of pixel of the image, number of bit of the analogic/digital converter, data type). Report the main features of the acquisition software (exposure time/frame rate setting, image average, greylevels histogram and data range, data type saved). Draw a sketch of the acquisition line with all the components and their position (X-ray tube, mechanical axis, detector, control computers) and describe the acquisition geometry.

**2. Preliminary acquisition of X-ray images and flat-field correction**

Radiography of an object. Set parameters of the X-ray tube (voltage and current) and see the different effects. Do the same with the digital detector (adjusting the frame rate and trying frame average). Acquisition of the detector background. Grab one image with X-rays switched off (also called “dark” image) and evaluate its average greylevel both on the image and on the histogram. Acquire the radiographic image with X-rays on without the object (also called “Izero”). Perform the normalization (or flat-field correction) process using ImageJ or other software taking into account of the physical meaning of the operation.

**3. Data acquisition for the characterization of the system**

*3.1 Linearity and signal to noise ratio*

**a)** acquisition of a set of images at increasing values of the current -with fixed voltage- in order to cover the whole range of greyvalues of the detector (the frame rate will not change too). In order to perform the flat-field operation on this dataset for each value of the current grab a single frame image as well as a 16 frames average image (always with X-rays on).

**b)** acquisition with fixed voltage, current and frame rate of a set of images for increasing image frame average values (starting from a single frame image and then for 2, 4, 8 ,16, 32 and 64 frames average).

*3.2 Spatial resolution*

Acquisition in the proper conditions (low voltage) of the radiographic image of a line-pair gauge, as well as the relative “Izero” image, in order to perform the direct evaluation of the spatial resolution of the system.

*3.3 X-rays attenuation measurement*

Acquisition in the proper conditions (high voltage) of the radiographic image of a calibrated aluminum step-wedge as well as the relative “izero” image.

**4. Data Elaboration**

*4.1 Linearity*

Verify that the response of the detector to an increasing X-ray current is perfectly linear. Do a table and a graph reporting the graylevel as function of the current for each image. Evaluate the average grey value on the image by selecting a ROI (region of interest) with ImageJ software.

*4.2 Signal to noise ratio*

**a)** Perform the flat-field correction on the whole dataset for increasing current values (dividing the single frame image by the 16 frames average image at each value of the current). Evaluate the average greyvalue and the standard deviation over a ROI with ImageJ. Calculate the Signal to Noise Ratio (SNR) for each current value and do a table and a graph reporting the SNR value as function of the current value. Verify that the best fit of the data is a power function with exponent 1/2.

**b)** Perform the flat-field correction on the whole dataset for increasing values of averaged frames (dividing each image for the image obtained at 64 frame average). Evaluate the average greyvalue and the standard deviation over a ROI with ImageJ. Calculate the Signal to Noise Ratio (SNR) for each image value and do a table and a graph reporting the SNR value as function of the number of frame average. Verify that the best fit of the data is always a power function with exponent 1/2.

***Optional****: calculate the number of effective graylevels as the integral between the background value and the maximum value of the power function obtained from the dataset of point (a) as the inverse of the standard deviation represented as function of the signal.*

*4.3 Spatial resolution*

**a)** Explain the meaning of spatial resolution for a digital detector and the meaning of the measurement unit “line-pair for millimeter” (lp/mm) as well as of the Nyquist frequency. Calculate the Nyquist frequency for the detector and compare to it the spatial resolution obtained with the direct method by means of the line-pair gauge.

**b)** Draw a horizontal line profile with ImageJ across the line pair gauge image and observe the typical decreasing amplitude for increasing spatial frequencies that appears. Write down the minimum and maximum values for each resolution group in the line-pair gauge image and calculate the modulation amplitude (difference between maximum and minimum). Normalize each calculated modulation amplitude to the zero frequency modulation amplitude obtained from a ROI taken on a side of the line-pair gauge (for minimum) and outside it (for maximum). Do a table and a graph reporting the normalized modulation values obtained as function of the relative spatial frequency in lp/mm and compare the obtained curve with the one derived from the Modulation Transfer Function calculated with the standard method (FFT of the Line Spread Function) given in the file “mtf.txt”.

*4.4 Attenuation of the X-ray beam*

**a)** Do a table and a graph of the normalized grayvalues as function of the aluminum thickness relative to the step-wedge attenuation measurement (it is more convenient to represent the normalized values in logarithmic scale). Observe the deviation from the pure exponential due to polychromatic beam effects (beam hardening). Fit properly the experimental data with an exponential curve and find out the value of the linear attenuation coefficient. Check on the NIST table which energy is related to this value and compare it to the expected energy value (between 1/3 and ½ of the maximum beam energy).

**b)** Evaluate with attention the Half Value Layer (HVL) of the X-ray beam.

**5. Conclusions**