Linearity of Flat Panel X-ray Detectors and Comparison of Non-Linear Correction Algorithms

Thomas HOFMANN [*], Joelle CLAUSSEN[*], Frank NACHTRAB[*,**], Ingo BAUSCHER[*],
Norman UHLMANN[*]

[*] Fraunhofer Development Center X-ray Technology EZRT, Fürth, Germany, a joint
department of the Fraunhofer Institutes IIS and IZFP
[**] Cluster of Excellence "Engineering of Advanced Materials", Friedrich-Alexander
Universität Erlangen-Nürnberg, Germany

Abstract. In this paper, investigations of the signal linearity behavior of flat panel detectors will be presented. Different correction algorithms were compared in reference to signal-to-noise ratio (SNR) and contrast sensitivity (CS). We will also show the influence of different methods to create the correction images (current variation vs. filtration). Moreover our results show that an adapted averaging, to achieve constant quantum statistics in the correction images, is advantageous.

1. Introduction

In industrial radiography and computed tomography usually flat panel X-ray detectors are used. Those detectors are built of thousands to millions of pixels. To achieve best possible image quality, all of these pixels must behave identically to the applied radiation ("flat field illumination"). Unfortunately irregularities in mechanical and electrical properties can entail strong differences in pixel behavior. In order to minimize pixel-to-pixel differences, there are several so called "flat field correction" methods. State of the art flat panel detectors are specified with a non-linearity of less than 1% [1]. In applications were this is tolerable a single point correction ("gain correction") can be applied. But in very low contrast applications advanced corrections are needed.

2. Linearity of pixel signal

To investigate the linearity of the detector, several flat field images (FFI) at multiple intensity levels were acquired. All images are offset corrected. The single pixel values were compared against the mean detector level for the different irradiation levels. A fit function $y = m*x$ gives information about the pixels sensitivity, and the coefficient of determination (R^2) about the linearity.
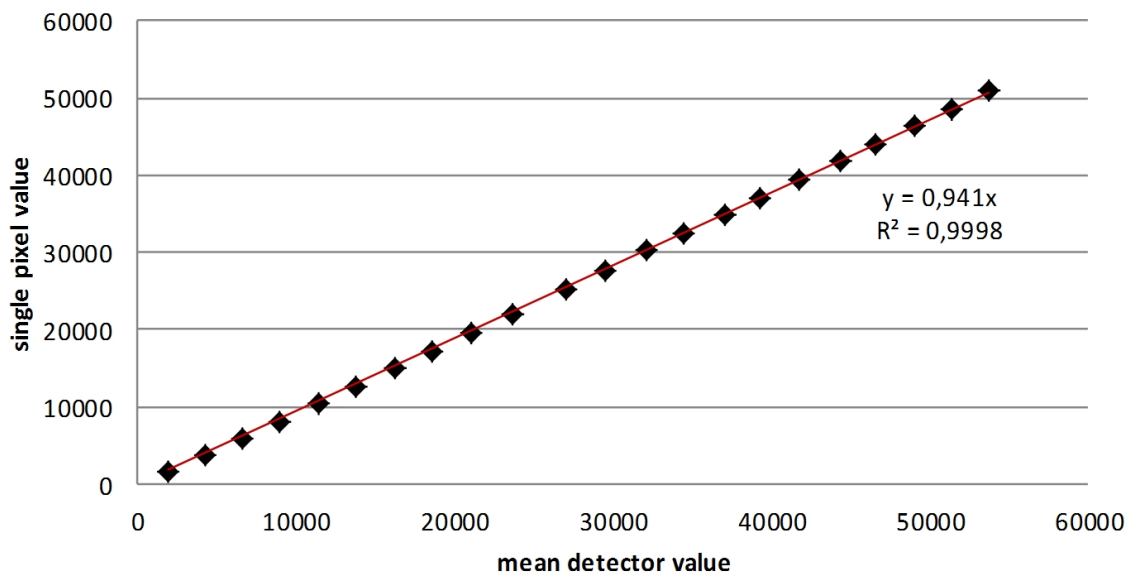
Figure 1. Single pixel value vs. mean detector value

As shown in Figure 1 there is a nearly linear, but not perfectly linear behavior between a single pixel value and mean detector value. The slope of the linear fit differs from 1, which is an indicator for the pixel to pixel sensitivity variation, but also of the spatial variation of the X-ray source. This value is comparable to the correction factor of a gain correction for this pixel. The R^2 value also differs from 1. This is a factor for the non-linearity of one detector pixel.
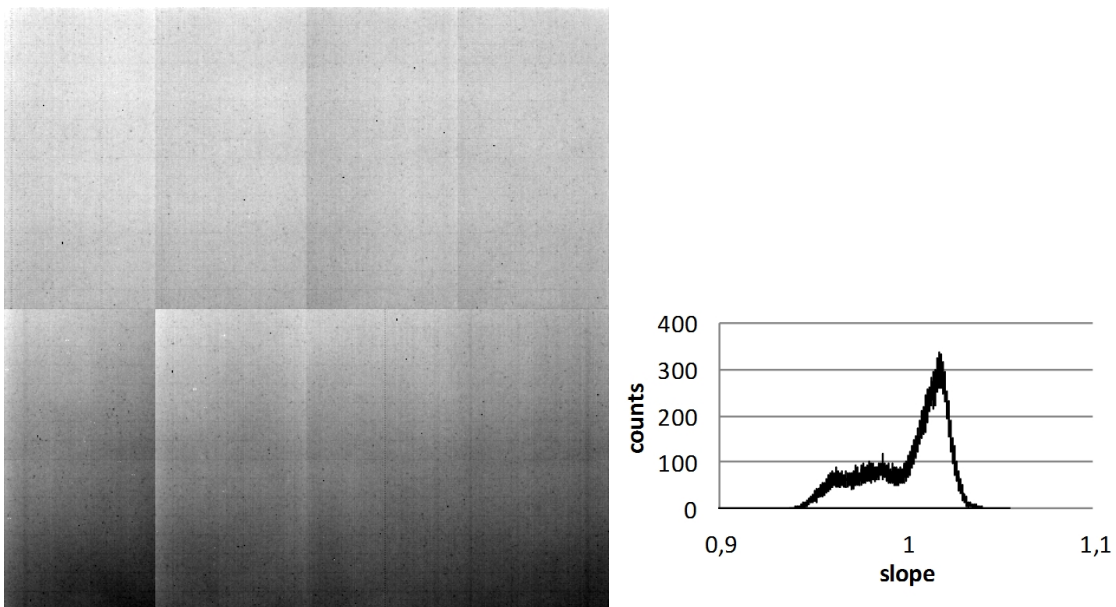
Figure 2. Distribution of slope values. Values are comparable to correction values of a simple bright correction. Effects of the readout electronics are clearly visible.
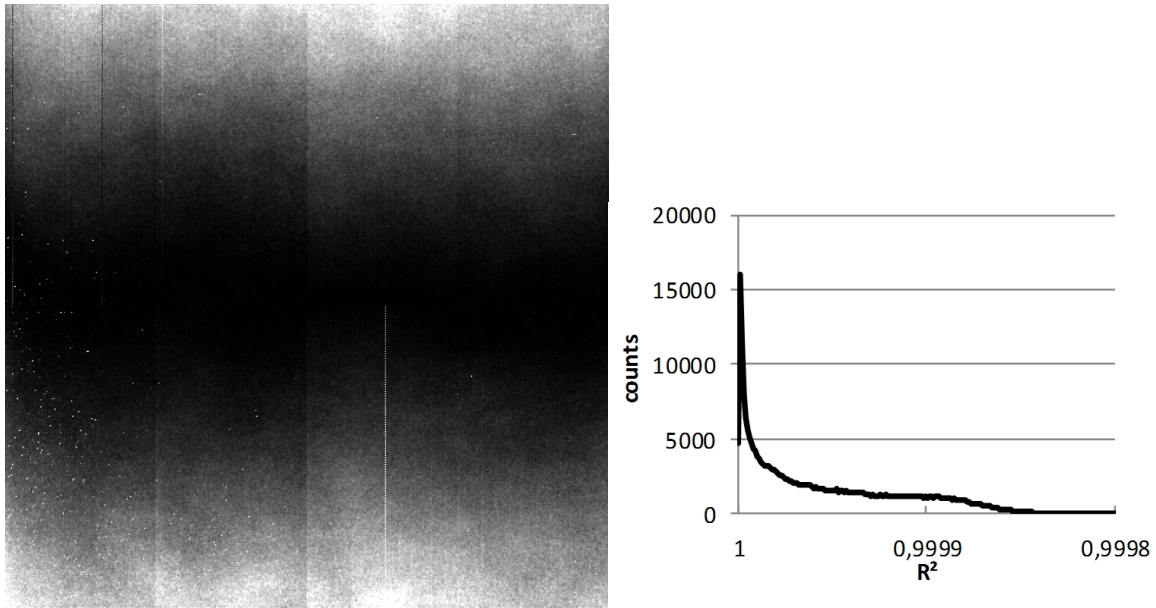
Figure 3. Distribution of R² values. The non-linearity increases towards detector edges.

Figures 2 and 3 show the spatial distribution of the calculated slopes and R^2 values for a typical industrial flat panel detector.

3. Methods for comparison

For evaluation of the non-linearity dependencies and their corrections, comparison methods are required. We expect effects at local (local impurities of scintillator and electronics) and at lager scales (extensive differences of scintillator and electronic qualities) which could influence the linearity. To investigate these effects over the whole dynamic range of the detector we choose the following methods:

3.1 Contrast sensitivity (CS)

For investigation of large scale effects we determine the CS similar to the ASTM E2597–7 standard [2]. It defines the minimum contrast difference in percent that can be detected. This is done with help of a aluminum step-wedge with grooves. In this method the difference of the mean signal is compared to the standard deviation of different areas per step. The lower the CS that can be achieved, the better is the correction.

3.2 Signal-to-noise ratio (SNR)

To address local scale effects, the SNR of several 50 x 50 pixel areas of the step-wedge image were determined per each step level and averaged.

4. Investigations

4.1 Comparison of different correction algorithms

Figure 1 shows that the pixel behavior cannot be fitted exactly with a linear function, like at the gain correction. Since the pixel response varies with the signal level, only one signal

level will be accurately corrected with this method. An improved linearity behavior can be achieved by using more FFIs with different signal levels and non-linear correction algorithms. Possible algorithms are polynomial fits or a piecewise linear interpolations between the multiple signal levels.
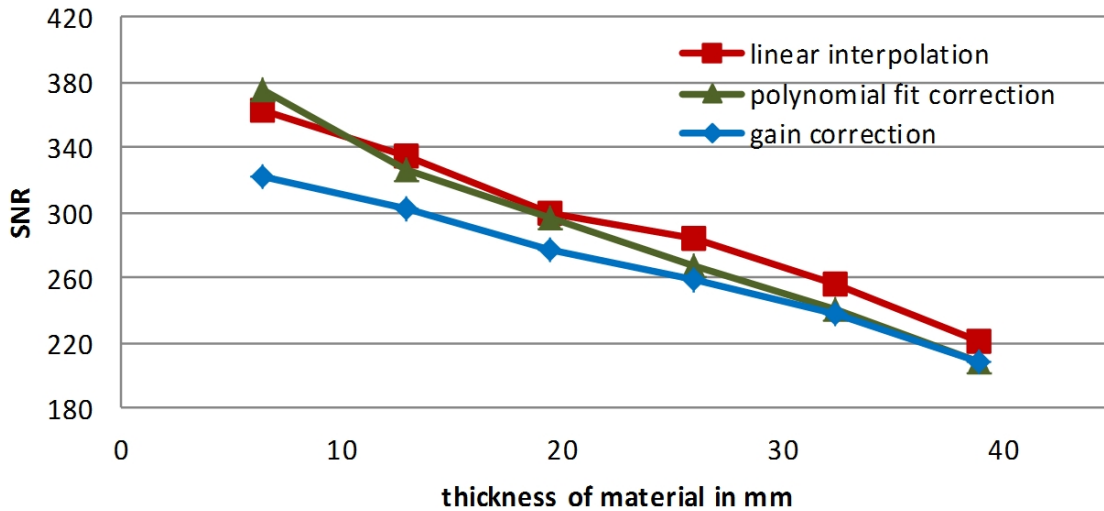

Figure 4. SNR in the corrected image in dependence of the penetrated material length for different algorithms
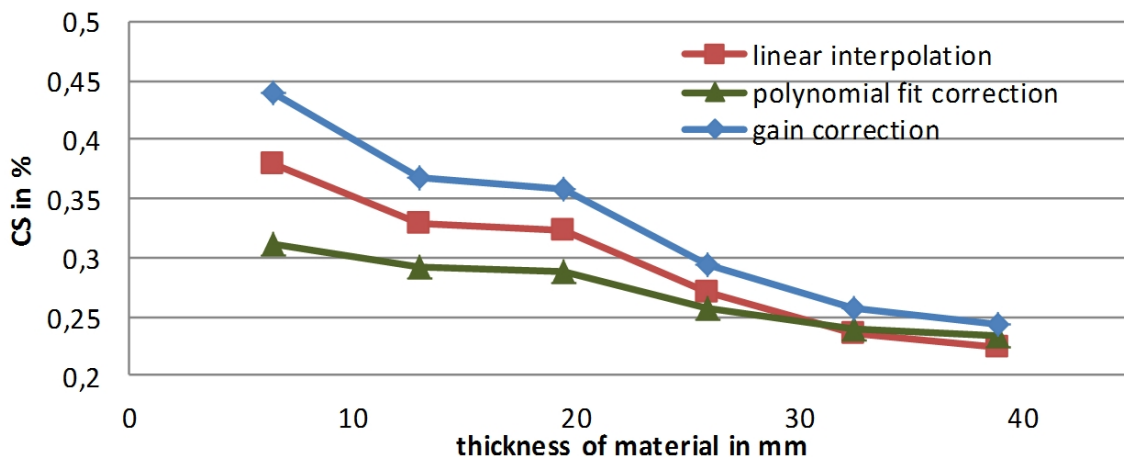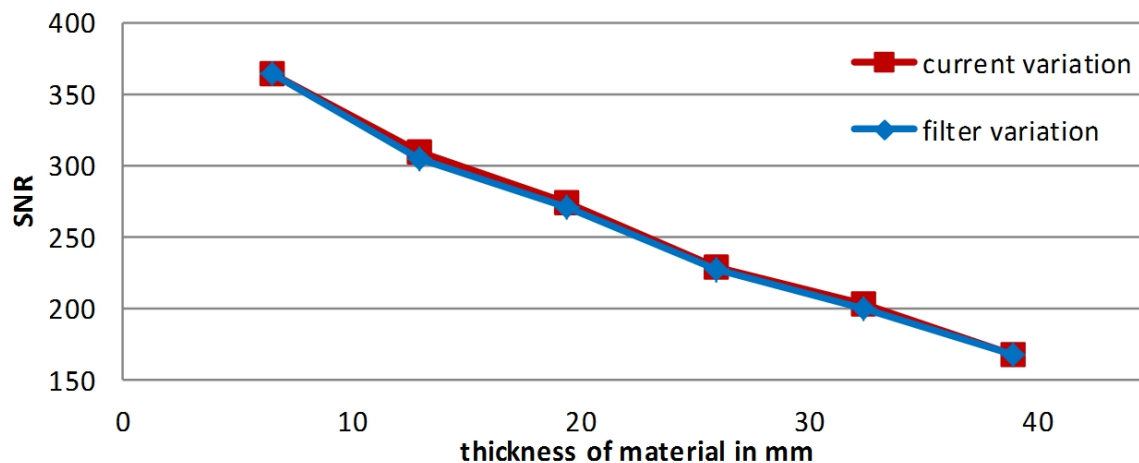

Figure 5. CS in the corrected image in dependence of the penetrated material length for different algorithms

As Figures 4 and 5 show, the simple gain correction works sufficiently, but is the worst one in comparison. The polynomial fit works well at high intensities, but reveals weakness at low intensities. The piecewise linear interpolation works best.

4.2 Comparison of FFIs for current and filter variation

Usually the multiple intensity levels, needed for the correction images are acquired by tube current variation. But in a real application, differences in intensity origins from variations of object thickness and composition of matter. Here also the spectrum gets hardened and changes with intensity. Acquiring of the multiple intensity level images at a constant tube current by changing the intensity through variation of filter thickness will already include such hardening effects.

Figure 6. SNR in the corrected image in dependence of the penetrated material length for current and filter variation
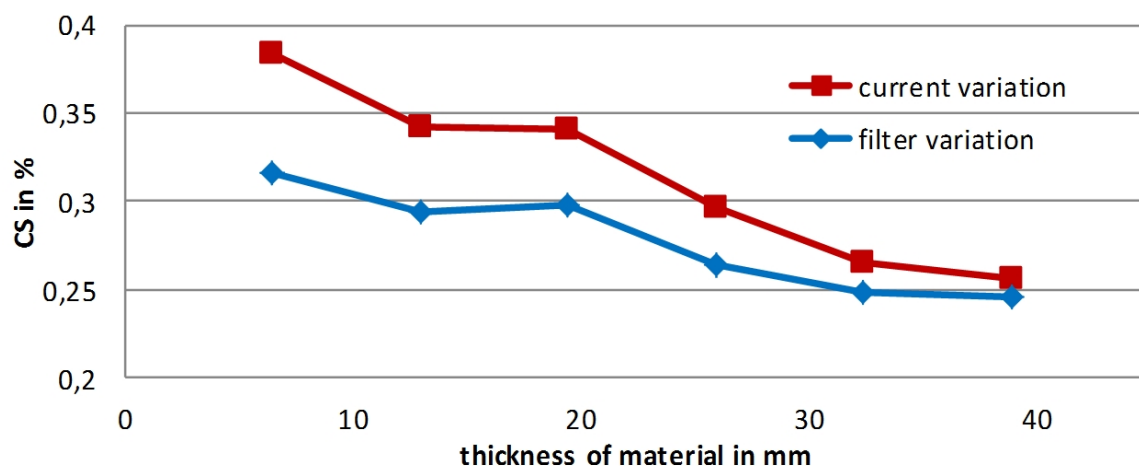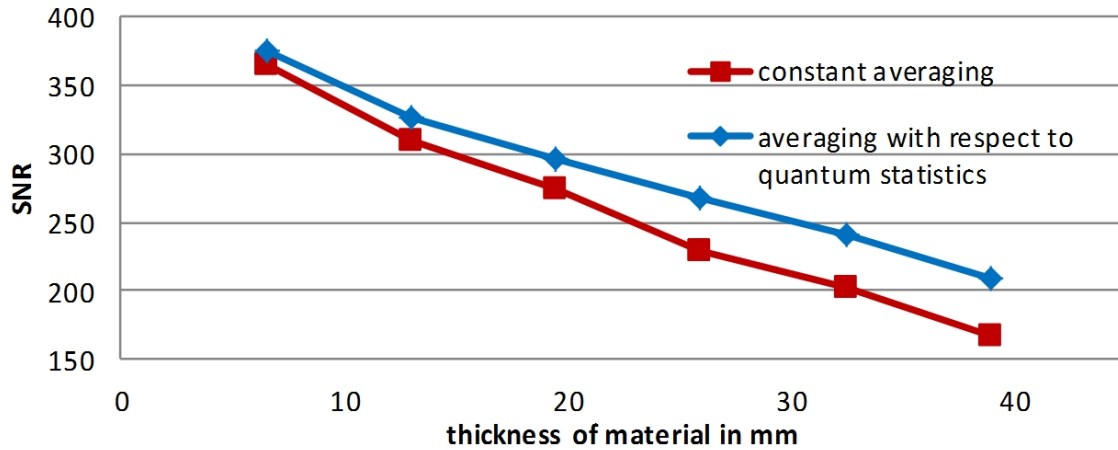

Figure 7. CS in the corrected image in dependence of the penetrated material length for current and filter variation

Figures 6 and 7 show a comparison of the different ways of generating the FFIs. The SNR is comparable, so the spectral behavior at near ranges seems to be similar. But there is a difference in the spectral behavior, which is shown in the CS. This could result from variation of the scintillator properties.

4.3 Influence of quantum statistic in FFIs

Due to the fact that the SNR increases with increasing number of X-ray photons, brighter images have a higher SNR. But for generation of the correction images usually a constant number of frames is acquired and averaged. Therefore darker correction images, with lower quantum statistics, lead to a lower SNR in dark regions of the corrected images. This effect can be reduced by increasing the number of averaged frames with decreasing signal level in the images, resulting in a constant applied X-ray dose for all correction images.

Figure 8. SNR in the corrected image in dependence of the penetrated material length for constant averaging and averaging with respect to quantum statistics
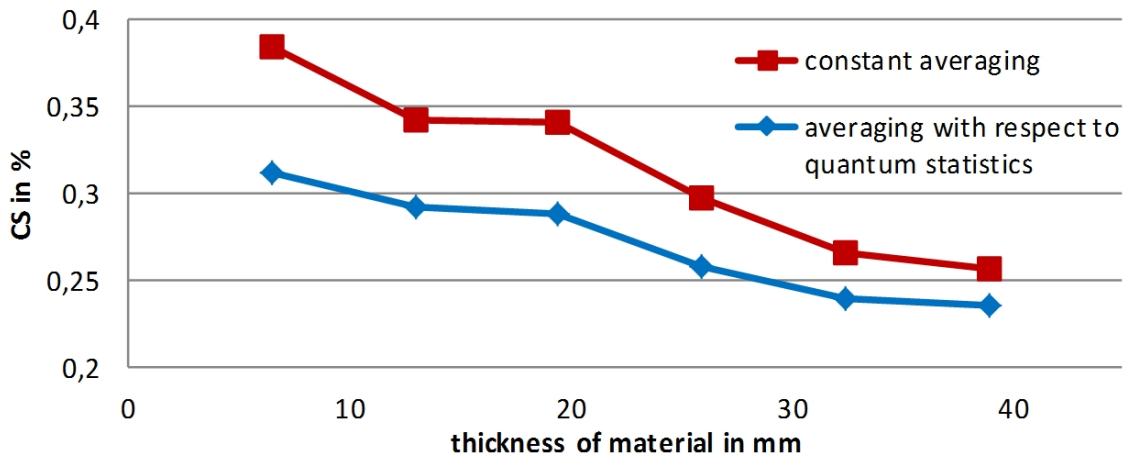
Figure 9. CS in the corrected image in dependence of the penetrated material length for constant averaging and averaging with respect to quantum statistics

Figure 8 shows a significant increase in SNR especially for lower intensity levels. This confirms the influence of quantum statistic in the FFIs. As shown in Figure 9 also the CS increase.

5. Conclusion

Compared to a simple gain correction a non-linear correction can improve the image quality in case of linearity and noise. Because of the non-linearity a piecewise linear interpolation works best for fitting the signal. The correction can be further improved by addressing the spectral response by generating the FFIs by filter variation. Especially in dark areas the noise could be decreased by an averaging depending on the quantum statistics.

References

[1] Perkin Elmer XRD 0820 AN 15 Datasheet Rev. 1
[2] ASTM E2597-7, Standard Practice for Manufacturing Characterization of Digital Detector Arrays