Low-Contrast Visibility in Flat Detector CT: A Simulation Study

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Introduction:

Flat detector CT suffers from a limited visibility of low-contrast objects. On the one hand this is due to increased image noise and x-ray scatter, on the other hand this can be attributed to a limited dynamic range of current flat detectors. Compared to clinical CT detectors with their energy absorption efficiency of 90% or more and their dynamic range of 20 bits or more, flat detectors with their energy absorption efficiency around 50 or 60% and their dynamic range of 10 to 12 bits above the noise floor [1] are significantly inferior. Further on, often intended or unintended over- or underexposure occurs in flat detector CT systems, resulting in undesired effects on image quality. To explore the situation we conduct a simulation study that systematically analyzes the effects of limited dynamic range and of over- or underexposure on CT image quality in general and on low-contrast visibility in particular.

Simulation:

We performed simulations in 2D parallel geometry with 512 projection angles ϑ and 512 rays ξ per projection. Prior to the reconstruction with a standard filtered backprojection algorithm, the ideal line integrals $p(\vartheta,\xi)$ obtained from those simulations will be manipulated in the following steps:

1. Relative Intensities

$$q_0(\vartheta,\xi) = e^{-p(\vartheta,\xi)}$$

2. Scaling Factor s

$$q_1 = q_0^s$$

3. Quantum Noise

$$q_2 = q_1 + N()\sqrt{q_1/I_0}$$

$N()$: Gaussian distributed random number with mean 0 and standard deviation 1.

I_0 : Number of detected quanta for the zero image.

4. Gain Factor g

$$q_3 = g\,q_2$$

5. AD Conversion and Saturation

$$q_4 = q_3 + U()\,2^{-b}$$

$$q_5 = \varepsilon \vee \frac{\lfloor q_4(2^b-1)+\frac{1}{2}\rfloor}{2^b-1} \wedge 1$$

$U()$: Uniformly distributed random number in the interval $[-\frac{1}{2},\frac{1}{2}]$.

b : Effective number of significant bits.

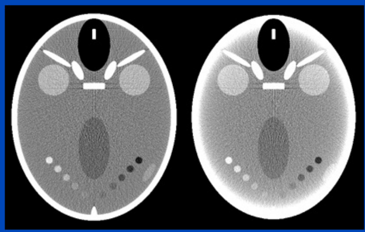

Fig. 1: Left: Standard image with gain factor g = 1. Right: Overexposed image with gain factor g = 4 as it would look without detruncation. (C/W) = (50/50).

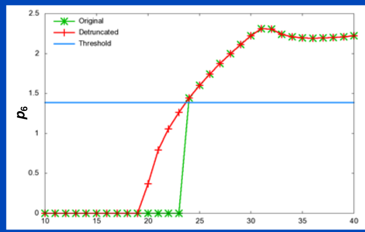

Fig. 2: Detruncation for the case of a gain factor g = 4. The detruncation must be performed since all attenuation values p_6 below a threshold of ln g will be set to zero.

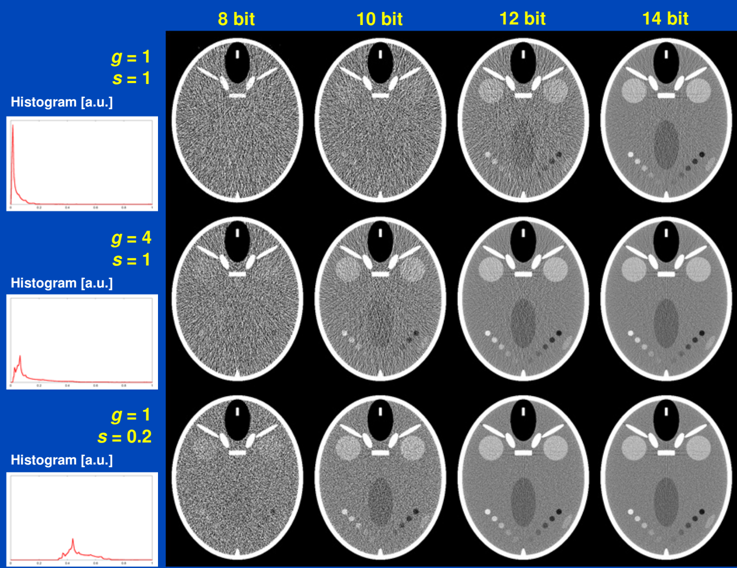

Fig. 3: Modified Forbild head phantom [3]. Top row: Gain g = 1, scale s = 1 (standard exposure, patient imaging). Middle row: g = 4, s = 1 (intended overexposure, patient imaging). Bottom row: g = 1, s = 0.2 (standard exposure, small animal imaging). From left to right: Histogram of analog signal q_3, b = 8 bits, 10 bits, 12 bits, 14 bits. (C/W) = (50/50).

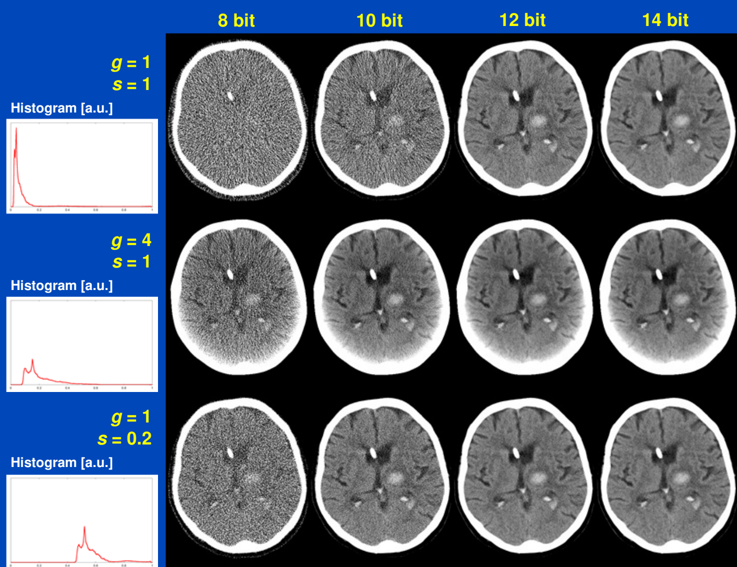

Fig. 4: Patient images of a cerebral hemorrhage with contrast agent. Same layout as fig. 3. (C/W) = (40/100).

6. Logarithm

$$p_6 = \begin{cases} 0 & \text{if } q_5 = 1 \\ \ln g - \ln q_5 & \text{if } q_5 < 1 \end{cases}$$

7. Detruncation

For a gain factor $g > 1$, a detruncation algorithm [2] should be applied (see figs. 1 and 2).

Results:

Figs. 3 and 4 show results for a modified Forbild head phantom [3] and for patient images from a forward projected clinical CT dataset.

It is interesting, but not surprising, that the images that are overexposed by a factor of g = 4 taken with b true bits are comparable to the images without overexposure taken at b+2 bits. Obviously, low-contrast detectability can be improved in certain situations by overexposing the detector.

It is also interesting to see, that the change in scale by a factor of five results in significantly different images. While the large patient data require a higher detector dynamic range, the small animal size data can do with less bits.

Summary and Conclusions:

We analyzed and demonstrated the influence of detector quantization and of overexposure on low contrast detectability. An analog gain factor will improve low contrast visibility at the price of truncation artifacts which must be corrected. Imaging on the scale of small animals requires a lower dynamic detector range than imaging on the larger scale of a patient. This might be utilized by applying an analog gamma amplifier prior to digitalization for patient imaging.

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References:

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