X-ray image sharpening by coincidence detection

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Abstract

In this paper we propose methods to realize coincidence detection in direct or indirect X-ray detectors. This coincidence is used to enhance the image sharpness.

Introduction

The Medipix collaboration [1] explored the possibility of using the information of multiple pixels detecting the same particle simultaneously. They demonstrated that the accumulated charge of a multiplicity of pixels can be combined to recover the particle's total ionization charge. Key in this operation is the detection of "coincidence", i.e. of hits that happen at the same moment in neighboring pixels due to the same event.

In X-ray imaging recovering the accumulated charge as such is in most cases not of interest. However there is an added value in the recovery of the loss of image sharpness that occurs due to the fact that the visible light flash caused by an X-photon in a scintillator spreads over multiple pixels (Figure 1).

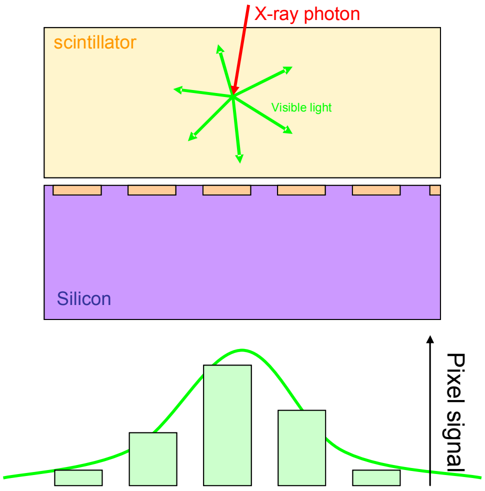

Figure 1 schematic cross section of a Silicon pixel array covered with an X-ray scintillator. A primary X-ray photon generates a flash of secondary visible light in the Scintillator.

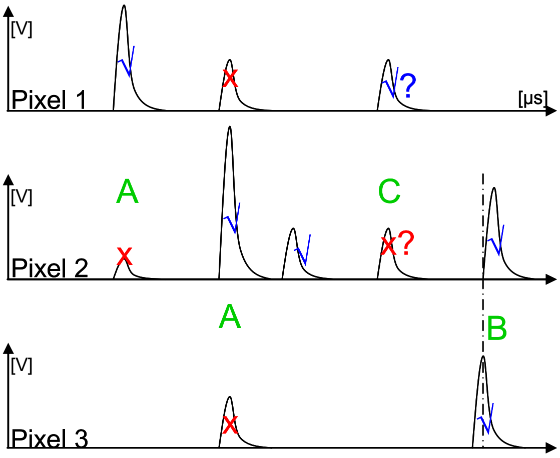

Figure 2 time trace of 3 neighboring pixels. Pulses, due to X-ray photons scintillating, arrive randomly in time. Pulse heights are proportional to the amount of secondary photons, or to the charge collected, in each pixel.

Sharpness recovery and theoretical effect on MTF

Figure 2 shows time traces of the secondary light pulses received by three neighboring pixels, whereby these light pulses are created by impinging primary X-ray photons as in Figure 1. In cases A and C the light hits multiple pixels simultaneously. In cases "A", pulses coincide on two or more pixels – the pixel with the highest pulse should prevail. In case "B", pulses in neighboring pixels do not occur exactly at the same moment, and should thus be treated as two distinct events. It is clear that an ambiguity may occur when the time delay between the two events is very short. Case C shows another ambiguity: if the two coinciding neighboring pulses are exactly equal in size, an arbitration circuit should choose – or a centroiding algorithm might be better suited.

The effect of the operator described is “sharpening”. We attempt to model its effect as an MTF improvement. The model of Figure 3 starts from the MTF of an ideal 100% fill factor square pixel. The effect of the Figure 1 blurring is modeled as a Gaussian blur, which is an imperfect model, but sufficient to serve the purpose of this paper. One sees e.g. that a Gaussian blur with $\sigma = 1$ pixel results in roughly a reduction of the spatial resolution with a factor 2. When using the MTF at Nyquist as a criterion one sees that a blur with $\sigma = 0.5$ pixels degrades the MTF (hence the DQE(f)) with a factor 2.
By recovering the pixel that has the central position of each secondary light flash, one cancels lateral optical crosstalk, and thus theoretically one recovers the ideal MTF.

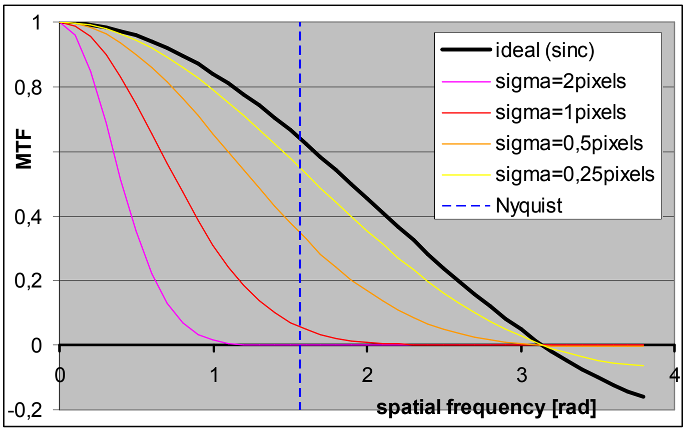

Figure 3 MTF of X-ray pixel with various degrees of blurring. Blurring is modeled as a Gaussian spread with its σ (standard deviation) expressed as a multiple of the pixel pitch. Thick black line: MTF of an ideal square pixel. Thin lines: MTF degraded by a superimposed Gaussian blur having a σ that measures 0.25 to 2 times the pixel pitch.

Sharpness recovering pixel topologies

We propose smart pixel topologies that can realize such sharpening operator. One can realize this operator in the photo charge domain (as in Figure 4), in the analog signal domain (as in Figure 5) or in the digital or binary pulse domain (as in Figure 6). Key in such operation is either a “winner-take-all” circuit (WTA) such as in [2][3], or linear (differencing, linear combination) or non-linear (maximum detection etc.) filtering.

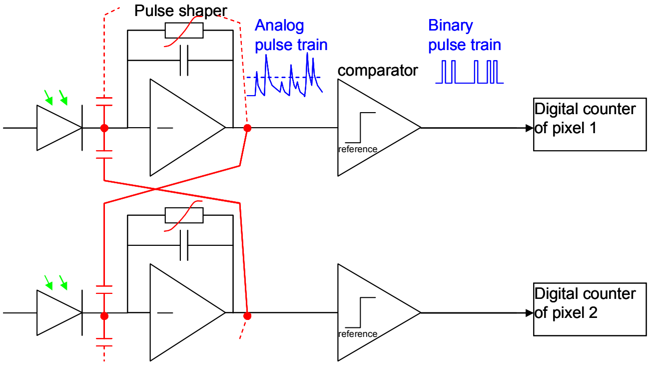

Figure 4 example of a circuit implementation of the sharpening operation in photo charge domain, shown with only 2 pixels. A pulse in a certain pixel suppresses via a cross-feedback capacitor the charge detection of a neighbor.

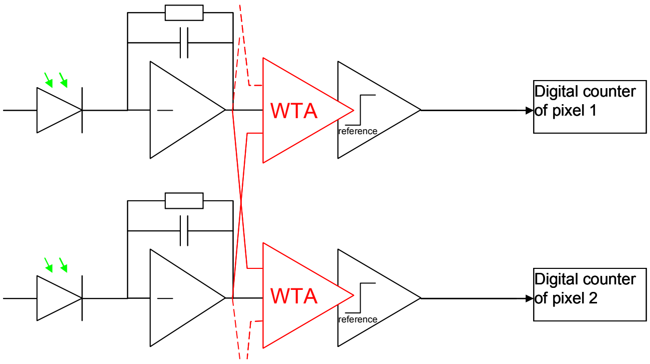

Figure 5 possible implementation in the analog pulse domain: a winner-takes-all circuit only propagates the pulse that is larger than its neighbors.

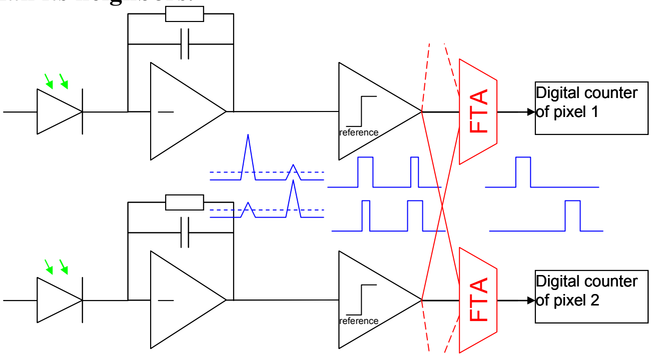

Figure 6 example of an implementation in the digital pulse domain with a "First-Takes-All" circuit: the pulse that comes firsts suppresses its neighbors. Obviously this assumes that the strongest analog pulse propagates first through the comparators.

Conclusions

Sharpening of an X-ray image by sharpening the image of each individual photon is a promising route. Theoretically it can cancel the MTF degradation due to the lateral spreading of the secondary light flashes of scintillators, as well as the MTF degradation due to other mechanisms.

References

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