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Real-Time Pulse Pile-up Recovery in X-ray Detector Data

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Many electron and X-ray microscopy applications place conflicting demands on detector sub-systems. These applications seek to maximise detector throughput at high count-rates at the same time as minimising pulse pile-up and maintaining accurate energy resolution. Traditional approaches to digital pulse processing typically require the user to trade-off degraded energy resolution against detector dead time.

This paper presents a digital pulse processing technology for processing the digitised output of X-ray detectors. Using a multi-stage, nonlinear digital signal processing algorithm this method is able to decode pile-up events in real-time, accurately characterizing the number, time-of-arrival and energy of all X-ray pulses in the digitised detector output. This digital pulse processing technology enables high count-rate operation with little dead-time, improved energy resolution and very high detector throughput, dramatically improving the performance of many electron and X-ray microscopy applications.

The performance of the nonlinear digital pulse processing algorithm has been evaluated over a wide range of input count-rates using both a digital nuclear pulse generator and a range of X-ray calibration sources. Implemented on a PCI based computer card, in a Virtex-IV FPGA, the digital pulse processing algorithm is able to decode pulse pile-up in real-time and is compatible with a wide range of X-ray detection systems.

Pulse pile-up is evident in the electrical output signal of an X-ray detector when events arrive within such a small time difference that the detector cannot recover sufficiently from the first radiation event to accurately detect subsequent events. Consequently the output signal, which ideally would consist of discrete pulses each corresponding to the incidence of a single radiation event, exhibits a waveform in which individual pulses overlap or "pile-up". In X-ray microscopy systems the effects of pulse pile-up include reduced throughput, system dead-time, and degradation of energy resolution, which can significantly inhibit overall performance [1], [2].

In order to fully characterise the output signal from the X-ray measurement process it is necessary to estimate the number, amplitude and time-of-arrival of incoming radiation events along with the impulse response of the detection process. The real-time pulse pile-up recovery algorithm requires a number of steps to accurately estimate the number, time of arrival, and energy of all radiation events in the digitised detector data. These steps are illustrated in Fig. 1 and explained below.

System Characterisation determines the system attributes unique to the particular X-ray detector and is required for accurate pulse localisation and identification.

Pulse localisation is performed on the input data stream in order to accurately determine the time-of-arrival of each radiation event.

Pulse identification uses the digitised detector output, the system characterisation data and the pulse localisation data to determine the energy of each pulse in the digitised X-ray detector output.

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Validation is the final functional stage of the algorithm. Using the output from the previous stages a model of the X-ray detector data is constructed and compared with the actual detector data. Statistical analysis of the residuals enables the algorithm to validate the energy of each event and discard from the final spectrum any erroneously estimated X-ray events.

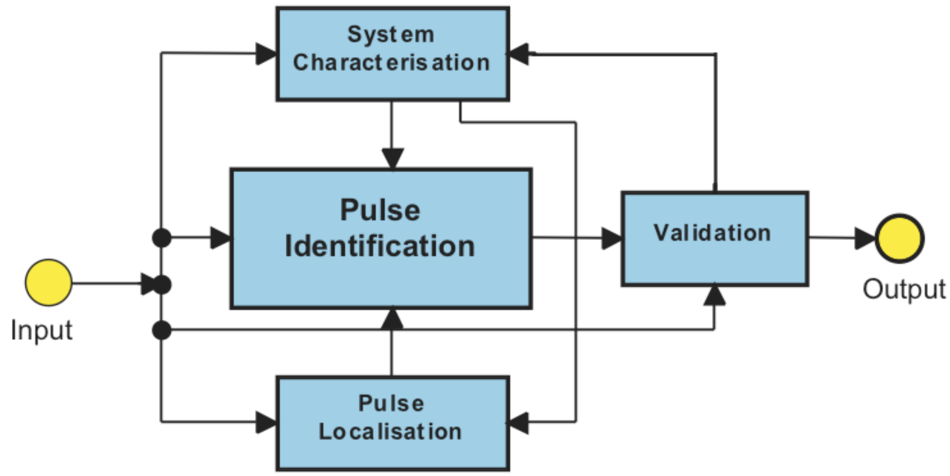

Fig. 1. A schematic overview of the digital pulse processing algorithm used to recover pulse pile-up.

The data from various stages of the digital pulse processing algorithm is depicted in Fig. 2. The digitised detector data is illustrated in (a) while the output from Pulse Localisation (identifying arrival time and energy of each event) is shown in (b). The reconstructed model of the X-ray detector data using the data from previous stages is depicted in (c) while the final sub-figure (d) depicts the residuals resulting from comparing the digitised detector data and the modelled data. Where the data has been poorly estimated (in this case around ADC sample 1,300) there is a clear spike in the residuals, this signal is used to discard X-ray events that have been inaccurately measured.

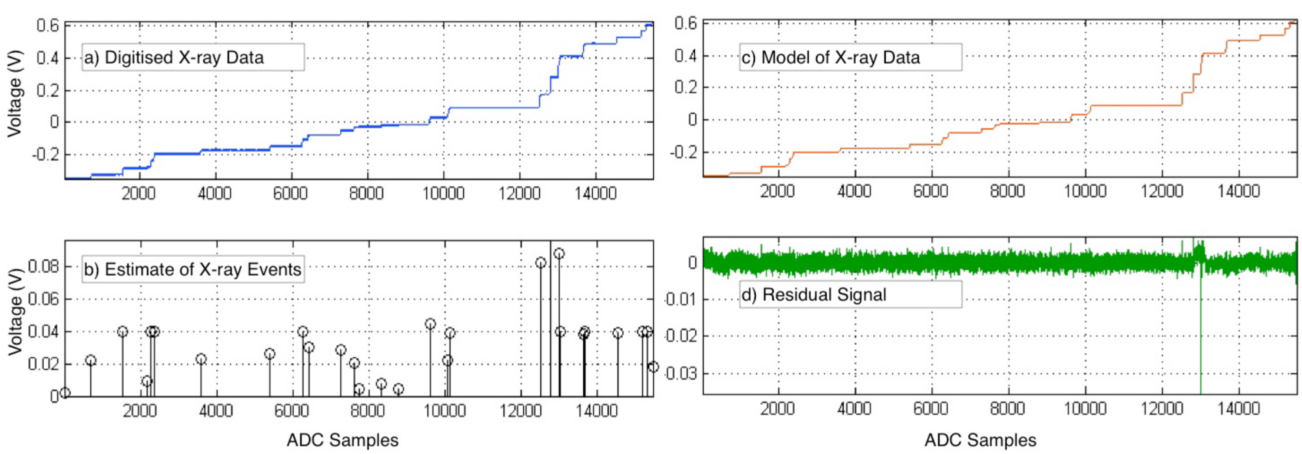

Fig. 2. The output data from various stages of digital pulse processing algorithm.

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