PARAMETER ESTIMATION& DIGITAL PEAK LOCALIZATION ALGORITHMS FOR GAMMA RAY SPECTROSCOPY

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ABSTRACT

In this paper, we discuss the problem of pulse pile up in Gamma-Ray spectroscopy. The aim is to estimate the different parameters of the basic pulse. A number of parameter estimation techniques for online peak localization are discussed. In particular, 3 and 4 point deconvolution algorithms and polynomial fitting of the pulse model are implemented. The set-up was tested with random signals from a ^{137}CS test source. Gamma pulses from a 3'' Na(TI) scintillation detector were captured as single and double pulses for testing. Purposes. The *deconvolution* using a 3 and 4 coefficient filters resulted in a resolution of pile-up to an average percentage of 93% *pileup* free. A polynomial of degree 8 and higher has been found to fit the Gamma Ray pulse accurately.

1. PULSE PILE UP IN GAMMA-RAY SPECTROSCOPY

A common problem in nuclear spectroscopy is pulse pileup caused by the non-zero response time of the detection system. For germanium detectors, the time required to collect all the ionization current associated with an event ranges from 0.5 to 6.0 μs [1]. The fact that pulses from a radiation detector are randomly spaced in time can lead to interfering effects between pulses when counting rates are not low. These effects are generally called pileup and can be minimized by making the total width of the pulses as small as possible.[2]. Pileup phenomena are of two types. The first type is known as tail pileup and involves the superposition of pulses on the long duration tail from a preceding pulse (see Fig 1). Tails can persist for relatively long periods of time so that tail pileup can be significant even at relatively low counting rates. A second type of pileup is the peak pileup, which occurs when two pulses are sufficiently close together so that they are treated as a single pulse by the analysis system [6]. From a practical point of view, we have found this pulse spacing to be best taken as approximately equal to the peaking time of the Gamma event. The peak pileup available in real Gamma pulses amounts to approximately 16% of the Gamma pulses captured. Researchers often simply reject pileup, when it is recognized [3]. In our case, we do not wish to lose the information associated with such events, so we use a 3-point deconvolution to separate the pulses.

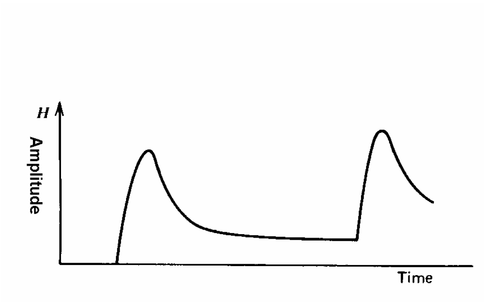

Figure 1. Pileup effect on a pulse peak from the tail of a preceding pulse

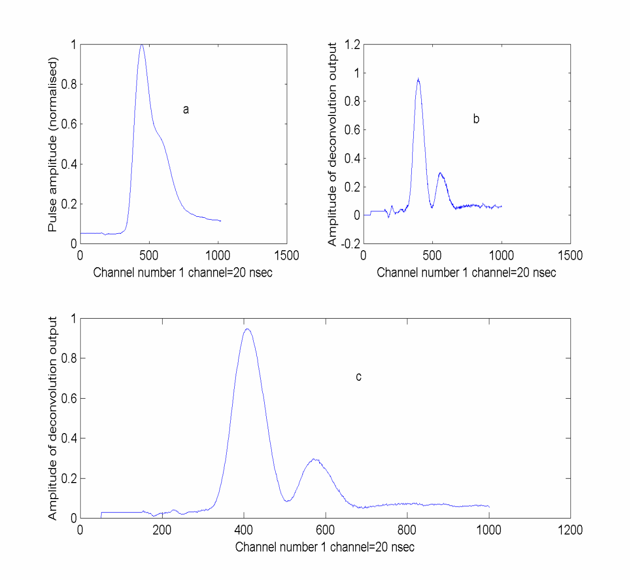

Figure 2. a) Shows a real pileup of two gamma ray events captured at ERL. B) Result of 3-point deconvolution. C) Result of 4 point deconvolution.

2. Peak detection using deconvolution

In many applications we are given an output signal from a system whose characteristics are known and require to determine the input signal. In nuclear spectrometry for instance, the semi-Gaussian shaping

amplifier acts as a convolving filter on the signal coming from preamplifier and causes an elongated tail
on the shaped signal, which makes it prone to pile-up. In such a case the problem is to design a corrective system which, when cascaded with the shaping system, produces an output that, in some sense, removes the effect of the shaper. The corrective system is called an inverse system and the operation is called deconvolution [2].
The deconvolution algorithm uses knowledge of the pulse shape to help locate and separate overlapping pulses. The pulse shape or the impulse response of the system has the following formula:

$$v(t) = t*\exp(-t/\tau) \qquad (1)$$

where τ is the shaping time constant. We have confined our system to a CR-RC to make the transfer function as simple as possible. It has been found that the inverse system of this preamplifier CR-RC shaper has the following three weights [4]

$$w1=(1/x)*\exp(x-1) \qquad (2a)$$
$$w2=(-2/x)*\exp(-1) \qquad (2b)$$
$$w3=(1/x)*\exp(-x-1) \qquad (2c)$$

where $x = \Delta t/\tau$ and Δt is the sampling interval. The deconvoluted output has the form :

$$S_k = w1*v_k + w2*v_{k-1} + w3*v_{k-2} \qquad (3)$$

This means that a filter performing this operation can be constructed by forming the weighted sum of three consecutive voltage samples in time. We have verified this by computing the inverse matrix of the impulse response matrix, which showed the weights are non-zero. A robust algorithm which maximises signal at the expense of some loss in time resolution is to make a sum of two deconvoluted samples. This is equivalent to using an algorithm with 4 weights which are easily calculated from the three original weights.

The 3-point deconvolution technique applied to tail pile-up events digitized at the ERL facility, succeeded in resolving pile-up by 93% in average, which means that 93% of the events after deconvolution were pileup free. However, deconvolution was not able to recover peak pileup, which is better rejected. Gamma Ray records captured at the ERL, showed a total pulse width of approximately 16µs, or 16t, where t is the pulse shape time constant. This means that the next event should not arrive within 16t, otherwise a signal pileup will occur. Hence for this particular case the maximum count rate or the maximum throughput of any pileup classifier is 1/(16t). For Na(Ti) detector this translates to a maximum throughput .06 Mcps [5].
We have used synthesised simulated data based on the impulse response of the CR-RC amplifier/shaper explained previously, and added 500,000 samples of white gaussian noise of variance of 3.55e-006. Applying the 3-point deconvolution on single Gamma pulses has resulted in the reduction of pulse width from 16t to approximately 4t,. This amounts to enhancing the maximum throughput of a pulse analyzer by almost 4 fold.. See figure 2 for the result of applying 3-point and 4-point deconvolution on real pile-up. The sharp fluctuations in the background shown in the deconvoluted pulse do not degrade the performance because they are outside the pulse window under study. See figure 3 for result of 3-point deconvolution on a simulated Gamma pulse after applying a 9-point moving average smoother to smooth out the noise added by deconvolution.

3. Polynomial fitting

Researchers have found that polynomial fitting of higher orders was a very attractive solution to the parameter estimation modeling problem since it exhibited linearity and followed their pulse shapes very well especially for slowly varying pulse shapes [7]. We have used simulation to investigate using polynomial filters to fit both the deconvoluted results and the real Gamma event by using the Chi^2 goodness of fit and sum of error square criteria from statistics. Due to the high computational cost of least square fit to the Gamma Ray established model, we found that a polynomial fit of 8-9th degree approximates the Gamma Ray event and can be applied on the *deconvoluted* events to give a Chi^2 of approximately 1.2 only. Figure 4 shows the relation between the degree of polynomial fit and the sum of error square. We observe from figure 4 that the least sum of error square corresponds to degrees 8-10. Fitting to degrees less than 6 is not acceptable at all. This result shows that a polynomial of degree higher than 8 does not only fit well to the Gamma Ray pulse model, but fits extremely well to the deconvoluted events. It is also clear that the sum of error square gives better results in the case of fitting a Gamma ray which is expected since the polynomials do not fit well near the narrow peaks. For polynomial of degree 8, the sum of error square was estimated to be less than 1% in the case of fitting a Gamma Ray.

4. CONCLUSIONS

A number of parameter estimation and digital online peak localisation algorithms are being developed for the purpose of Gamma Ray pulse identification in absence of noise and *pileup*. A 3-point and 4-point *deconvolution* techniques have been successfully tested and compared and found to resolve pile-up up to 93%. The 3-point deconvolution gave a maximum throughput of the pulse analyzer of almost 0.25 MCPS, amounting to an enhancement by 4 fold compared to the Gamma Ray. The pulse shape of the Gamma ray was found to approximate very well to a polynomial of degree 8 and above, leading to a Chi^2 goodness of fit of approximately 1.2. Work is under progress to implement the parameter estimation algorithms in real time using DSP processor.

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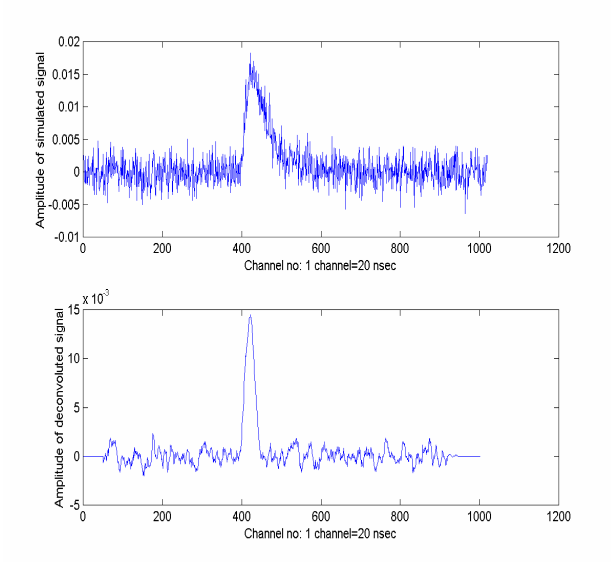

Figure 3. Result of applying 3-point deconvolution on simulated Gamma Ray after filtering with a 9-point moving average filter.

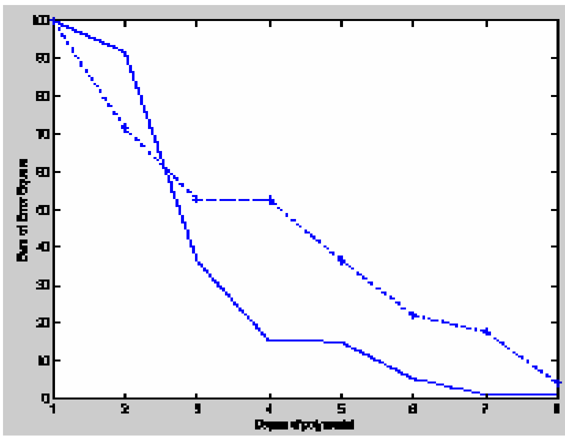

Figure 4. Effect of degree of polynomial fit to 3-point deconvolution output on the sum of error square. The solid line shows fit to a typical Gamma Ray, and dotted line fit to the result of 3-point Deconvolution.