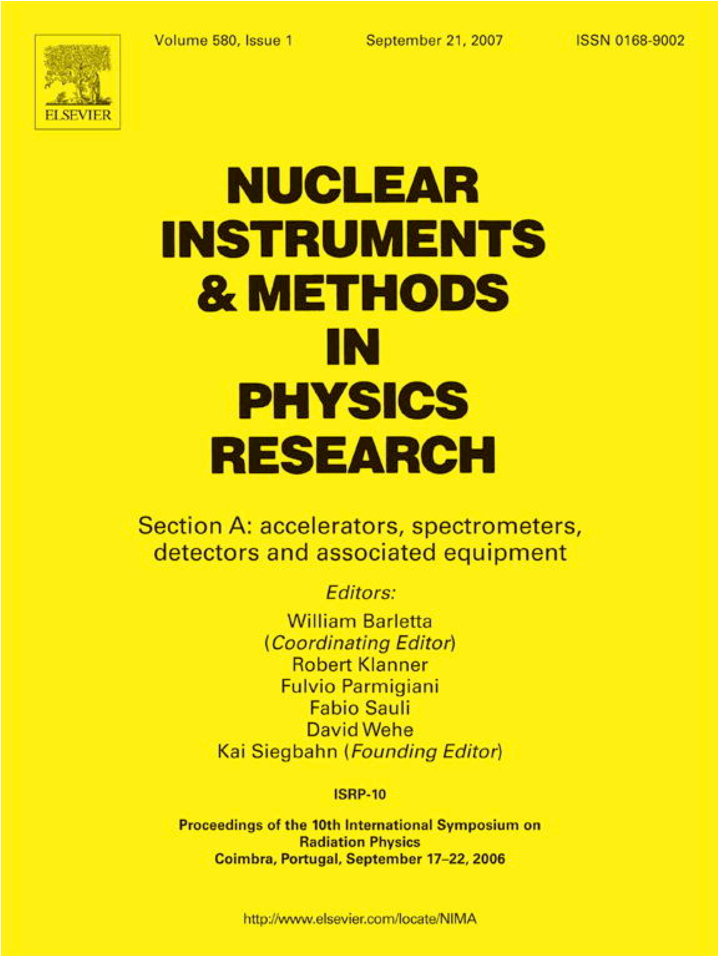
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Data acquisition system development for the detection of X-ray photons in multi-wire gas proportional counters

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Abstract

A new data acquisition system coupled to a backgammon-type gas proportional counter capable of single-photon counting over a wide range of count rates has been developed and replaces a CAMAC-based system. The new apparatus possesses improved architecture, interface technology, speed and diagnostic capability. System efficiency and throughput is significantly improved, especially in addressing earlier problems of hardware buffer downloads containing zero or repeat data and inefficient gating control. The new system is a PXI-based data acquisition apparatus including additional electronics, controlled by a graphical programming environment. It allows development of superior diagnostic tools for system optimisation and more stable performance. System efficiency is improved by 10% over a wide range of count rates (0.5 Hz–50 kHz). For the Backgammon Detector type, this represents a significant improvement in performance and applicability over previous systems. Characteristic and few-electron spectra collected on the new acquisition system are illustrated.

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Keywords: Data acquisition; X-ray detectors; Photon counting; Electronic signal processing; X-ray spectroscopy

1. Introduction

Coupled to the wide variety of sensors and detectors, analogue and digital signal processing and data acquisition has played an essential role in experimental physics. Recent development of digital processing systems where raw signals are directly digitised and processing is software based [1–3] are beginning to show an impact, but current trends complete most of the signal processing prior to digitisation. These data acquisition systems are still crucial and continue to play an important role in experimental physics.

The X-ray Optics group at the University of Melbourne have described a Johann-type curved crystal X-ray spectrometer that was employed for critically testing Quantum Electrodynamics in highly charged medium-Z systems [4,5]. A backgammon-type multi-wire gas proportional counter (MWPC) was used to detect X-ray photons in two dimensions using a combination of resistive and capacitive charge division. We here detail a new low-cost, high performance data acquisition system overcoming speed and buffer limitations for Backgammon Detector applications.

2. Earlier operation

The system acquires four signals from the detector (for every photon detected) to achieve two-dimensional encoding. The electronics and data acquisition system are designed to cope with a wide range of count rates (<0.5 Hz and >50 kHz) and discriminates against signals originating from low or high-energy photons.

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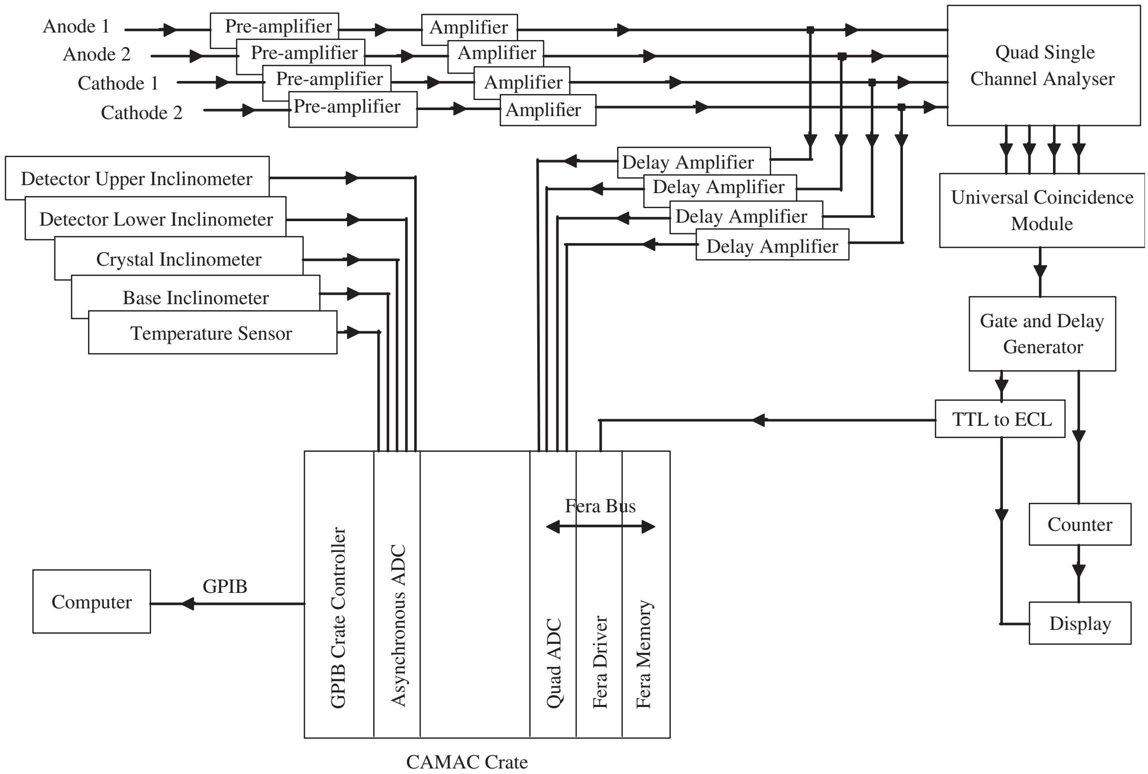

Fig. 1. Schematic of the prior data acquisition system: detector signal processing electronics, inclinometers, Pt resistance temperature sensor and a CAMAC data acquisition chassis controlled by a PC. The control software is K-max version 6.6.1f (Sparrow Inc., USA).

An expanded electronics and data acquisition system acquires inputs from the experimental spectrometer in addition to the detector acquisition system [4]. The additional instrumentation includes four inclinometers (to collect spectrometer theta, 2-θ and base angle data) and a Pt resistance temperature sensor. This data acquisition system is shown in Fig. 1. The detector signal acquisition is triggered by the electronics on a coincidence condition and data are simultaneously acquired on four channels. Detector signal processing electronics, data acquisition configuration and operation are described in detail elsewhere [6]. Signals do not require simultaneous sampling, so a fast multiplexer coupled to a scanning A/D converter (16 bits resolution without S/H circuitry) is used (Kinetic Systems model 3516). Each channel acquisition requires 250 μs (therefore, five channels require 1.25 ms) so individual rates are kHz or pooled sampling rates of 100–500 Hz. Inclinometer and temperature channels are asynchronously scanned while the hardware buffer is filled with detector data. The system digitises detector and sensor data, stores and processes raw data, and displays detector and spectrometer position information. These functions were programmed using the instrument control and data acquisition software program K-max (Sparrow Inc., version 6.6.1f).

3. Issues for development

The previous system (Fig. 1) performed adequately, however under certain circumstances deficiencies were apparent. Due to asynchronous digitisation, inclinometer and temperature signal acquisition was dramatically compromised by high detector fluxes. During spectrometer calibration, detector count rates range from 500 Hz to 10 kHz. Multiple detector data transfers across the CAMAC-PC interface commonly occur each second, resulting in interruption to inclinometer data acquisition.

Coupled with this restriction is the requirement that control commands from the PC be transmitted across the interface, further slowing acquisition time. Thirdly, the data acquisition program accessed a number of external subroutines essential for sorting and processing but in an inefficient manner. These three aspects combined to limit the acquisition of the inclinometer/temperature data in this operational mode to 1–100 Hz.

Transfer of data from hardware buffer is commonly facilitated by a single block transfer of the entire buffer contents across the CAMAC-PC interface. This apparently efficient data transfer method is compromised if the buffer is only partially filled during a fill-and-transfer cycle, by significant amounts of zero or old data being transferred along with the newly added data. Algorithms can be run post-acquisition to search for zero or duplicate data, but are a needless complication. Efficient, simple and robust diagnostic tools are essential when analysing signal output for system optimisation and problem solving. The earlier control software restricted the system's 'real-time' diagnostic capability and considerable effort was required to generate diagnostic software routines for signal, digitisation and data transfer analysis. Hence several limitations affected the prior performance of the detector and inclinometer/temperature acquisition subsystems.

4. New apparatus

The new data acquisition system includes four additional linear gate and stretchers, an extra gate and delay generator and a new data acquisition chassis (Fig. 2). The chassis is a PXI-based system (National Instruments model NI PXI-1031) with two digitisers. The first is a 3 MHz four channel simultaneously sampling 14-bit digitiser (NI PXI-6132) used for detector data acquisition. The second, for inclinometer and temperature data acquisition, is a 1.25 MHz 16 bit 16 channel scanning digitiser (NI PXI-6250). Four linear gate and stretchers (Ortec model 542) sample-and-hold the amplified, shaped and delayed signals. The output from the first gate and delay generator (Ortec model 416A), indicating a coincident event, triggers the input gate for each linear gate and stretcher. The second gate and delay generator (Ortec model 416A) triggers the detector data digitiser. Precise timing of all trigger pulses is required for the system to function optimally.

The PC is remotely connected to the PXI chassis via a high-speed serial MXI-4 interface (National Instruments model NI PXI-PCI833x) that is capable of a sustained data transfer rate of 78 MB/s. In addition to the main function of hardware control, the software program LabVIEW (National Instruments, version 7.1) is used to transfer, store, process and display the data. Test signals generated from the pre-amplifiers were used to optimise the signal processing electronics. Further testing assessed the functionality, performance, stability of the new acquisition system.

5. Results and discussion

Good statistics are vital for highly precise energy assignments. After optimisation of the signal electronics, the initial assessment of the data acquisition system was successful, and a number of details became apparent that were previously undetected due to the limited diagnostic capability in the CAMAC-based system. Robust diagnostic tools are need to analyse signal output for system optimisation and problem solving. The new control software addresses the system's 'real-time' diagnostic capability and generates diagnostic software routines for signal, digitisation and data transfer analysis. The new system easily interrogates individual channels, sources of noise contributions, buffer errors and impedance mismatch by providing all outputs quickly and independently. Fast sampling rates assess spectometer mechanical robustness by the inclinometer frequency spectrum. For example, delay and gating optimisation and impedance mismatch issues were all much more readily identified. Zero and repeat data problems previously observed in the CAMAC-based hardware were avoided by removing the hardware buffer.

The acquisition efficiency of the new system was stable at $98\pm0.5\%$ tested over the counting rate range 1 Hz–50 kHz. This is a significant improvement over the old system where the data acquisition signal loss was $>10\%$ for detector data only acquisition and was count-rate dependent.

A backgammon-type MWPC coupled to a Johann spectrometer X-ray spectra collected data both at low and moderate fluxes demonstrating the versatility of the system. Fig. 3 illustrates clean two-dimensional V Kα characteristic spectra (following Refs. [7,8]). This was recorded at 3.3 kHz. High quality is emphasised in the histogram (Fig. 4). Fig. 5 shows a single helium-like

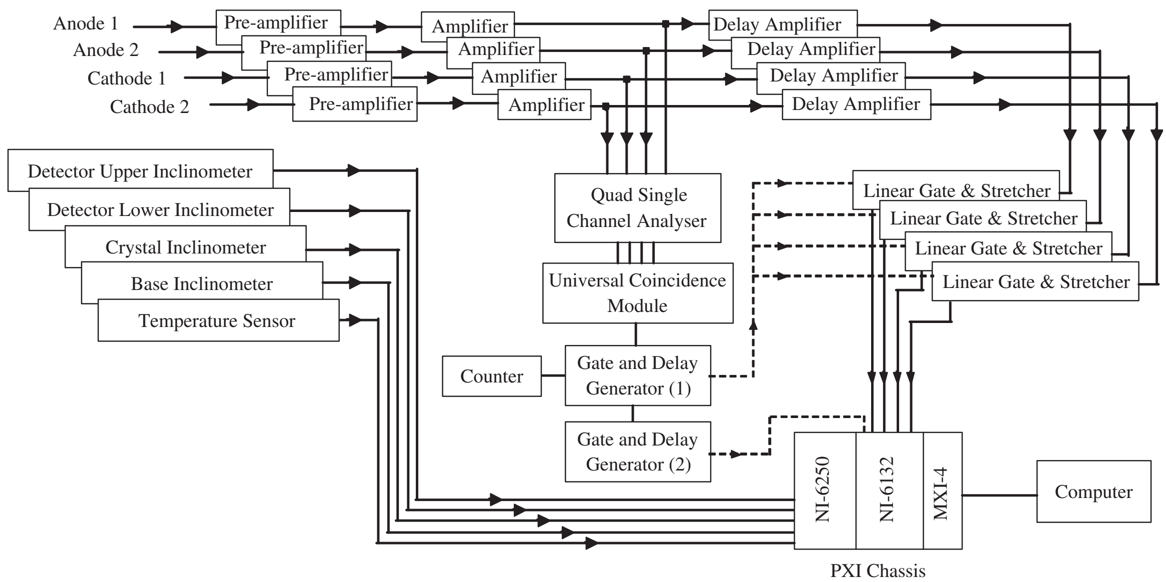

Fig. 2. A schematic of the new data acquisition with the addition of four linear gate and stretchers and a new PXI chassis controlled by the commercial software program LabVIEW. The dotted lines denote the trigger lines.

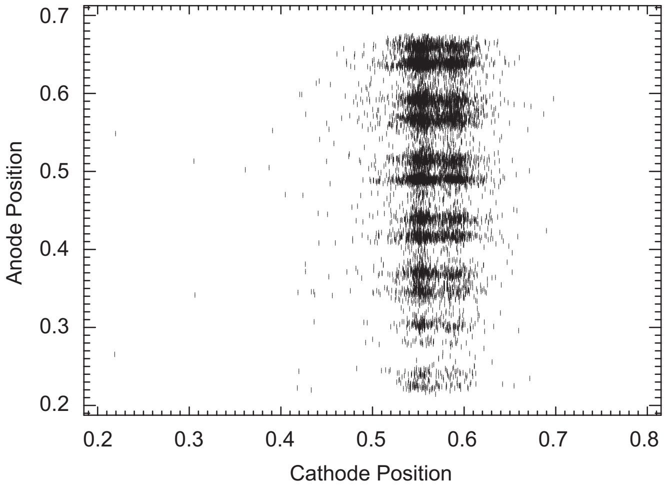

Fig. 3. Detector image of characteristic V Kα1 and V Kα2 doublet monochromated by a Johann curved crystal spectrometer.

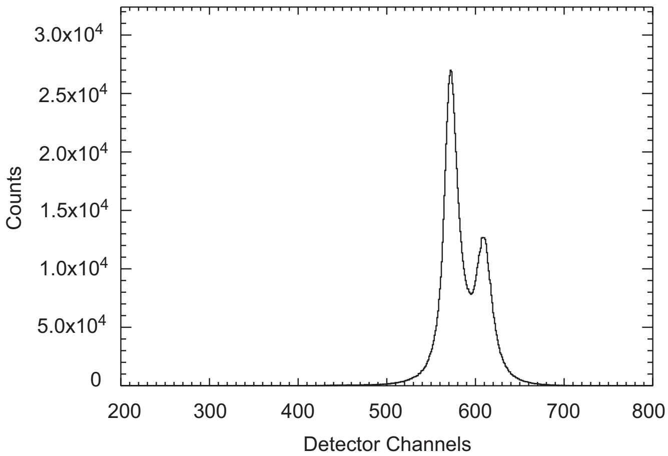

Fig. 4. Histogram of the characteristic V Kα output showing well-separated peaks. This spectrum was accumulated at 3.3 kHz in 5 min.

titanium spectrum collected from the Electron-Beam Ion Trap facility at NIST, Gaithersburg, extracted from an experiment covering several days. This spectrum was recorded from a single-data file collected at ~0.6 Hz. Background noise levels can dominate. The main peaks are nonetheless clear in the data despite the low signal. This is a useful test illustration of the data acquisition system. Data integrity is often a significant problem with such low count rates especially in a (hardware) buffer-controlled download; this illustration shows an extreme of such a test application, in a quite different regime compared to Fig. 3 and with high resolution (limited by X-ray diffraction

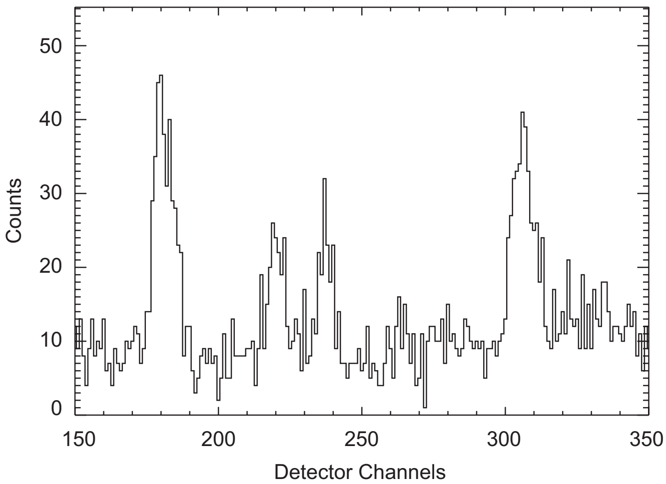

Fig. 5. Histogram of a single He-like titanium spectrum. Data collection time was 2.3 h at approximately 0.6 Hz. The full data set collected data for several days.

instrumental widths) showing a clean low background from all causes including dataway losses and coincidence failures.

The new control system coupled with our signal acquisition electronics is a significant innovation for *backgammon detector* applications generally. In particular, we obtain significantly superior performance compared to an established system; and a dramatic improvement of diagnostic capability and correction time, especially in an on-line experimental situation. We acknowledge the ARC and MNRF in supporting this research. E.T. and B.R. were partially supported by the Hungarian Science Fund (No: OTKA T046454).

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