A Digital System for Image Acquisition and its Application to X-ray Detection

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A digital system for image acquisition is described. which is able to process two electric signals of amplitude varying from 0 to 10 Volts and correlate them in a two dimensional histogram. X and Y coordinates for every event are derived from the amplitudes of two coincident - within an AND gate transition time - pulses. The system is composed of two Analog-to-digital Converters (ADC's), control electronics and a coincidence gate generator, implemented in a card that is plugged to any IBM compatible PC ISA bus. Data acquisition rate may be as high as 3.6×10^5 events per second in computers equipped with Pentium 233 MHz processor. Software code has been written in the Delphi environment using Assembly routines. Image size may be chosen from 256×256 to 1024×1024 pixels. Images are shown that illustrate the applicability to detection systems based on two dimensional position sensitive X-ray detectors.

Um sistema digital para aquisição de imagens é descritos, capaz de processar dois sinais elétricos de amplitude variando entre 0 e 10 Volts e correlacioná-los em um histograma bidimensional. As coordenadas X e Y para cada evento são derivadas das amplitude de dois pulsos coincidentes - dentro do intervalo de transição de uma porta AND. O sistema é composto de dois conversores analógico-digital, eletrônica de controle e um gerador de porta de coincidência, implementados em uma placa que é conectada ao barramento ISA de computadores compatíveis com o IBM-PC. A taxa de aquisição de dados pode atingir 3.6×10^5 eventos por segundo em computadores equipados com processador Pentium 233 M Hz. O código fonte foi escrito no ambiente Delphi usando rotinas em linguagem Assembly. Tamanho de imagem pode ser escolhido de 256×256 até 1024×1024 1024 pixels. São mostradas imagens que ilustram a aplicabilidade a sistemas de detecção baseados em detetores de raios-X sensíveis a posição bidimensionais.

I Introduction

The need for image acquisition is present in different fields of activity, from scientific research to medical applications. The importance and power of image acquisition instrumentation is more evident if it is regarded as a two parameter multichannel analyser. In contrast to image treatment, that is usually an off-line procedure, image acquisition is most often expected to be an on-line operation, that means it should be carried out during the data generation. This feature requires critical attention in the instrumentation development to parameters such as sampling rate, resolution, timing, linearity.

Commercial PC interfaces for data acquisition have been available for the last 20 years, which make use of a microprocessor that handles the process of digitizing the amplitudes of electric signals and converting them to a memory address that is histogrammed [1,2,3]. These are multichannel analysers, providing single parameter information (one dimensional spectra). The data acquisition rate in these devices is below 105 events per second.

At least two solutions for two parameters acquisition have been made commercially available [4,5], however not including the ADC's in the PC interface board. In these cases, data has to be digitized before being .sent to the microcomputer. A PC image acquisition interface including on-board ADC's, micro-processor and memory has been developed at the *Laboratório Nacional de Luz Síncrotron* (LNLS) for laboratory use [6]. As expected, the data acquisition rate in this case is not much higher than in the case of single parameter acquisition referred to above, since it is based on the same technique. Other solutions have been reported that are not implemented on the PC bus, and rely on fast time-to-digital techniques to achieve data acquisition rates close to 10^6 events per second [7,8].

The main reason for using a dedicated microprocessor in PC image acquisition interfaces is to acquire data independently of other applications running in the computer, so as to provide faster data sampling. However, the speed of PC microprocessors has been considerably increased in the last 5 years, so that it is now possible to address the question of designing a PC image acquisition interface that needs no dedicated processor and is yet suitable for standard applications. The present work includes description, characterization and application of such an interface, developed recently.

II Hardware Description

Two input analog signals - corresponding to the coordinates of one event - of amplitudes ranging from 0 to 10 Volts are split to two comparators and two ADC's. The outputs of the comparators are sent to an AND gate that enables, after a time interval δ, the ADC's conversion operation. In practice, the X and Y signals may not to be simultaneous, a time interval ϵ existing between them. In order for the device to operate properly, the time width of the analog signals must therefore be greater than ϵ (See Fig. 1).

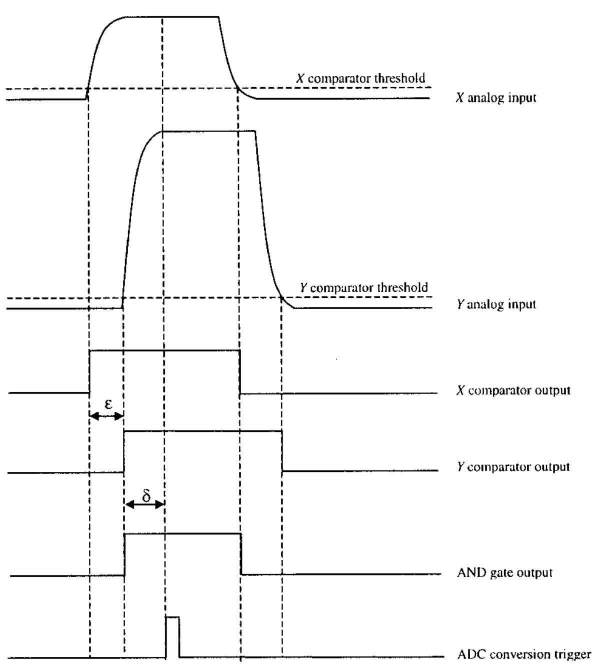

Figure 1. Timing signals diagram.

The used ADC's (AD1671) feature 12 bits resolution and - 800 ns conversion time. At the end of each conversion, the ADC's prompt an 'end of conversion' (EOC) signal which indicates to the PC bus that an event is available for histogramming. This condition is in fact signaled by an AND of the two individual ADC's 1end of conversion' signals. The interval δ must be chosen so that the amplitude of the analog input signals is stable when ADC conversion is started. These timing signals are illustrated in Fig. 1.

Once a conversion is finished, twelve bits from each ADC are latched to the PC I/0 data bus until data is read by a software command. Since we are using 16 bits data bus, two read operations are done for each X&Y conversion. Data is then histogrammed and stored in the PC RAM. Data histogramming and memory storage are done by use of software comands. The main circuit diagram is sketched in Fig. 2.

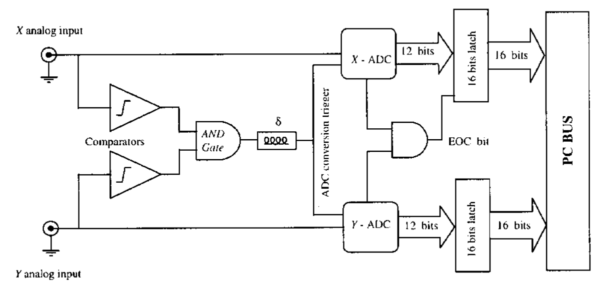

Figure 2. Main circuit diagram.

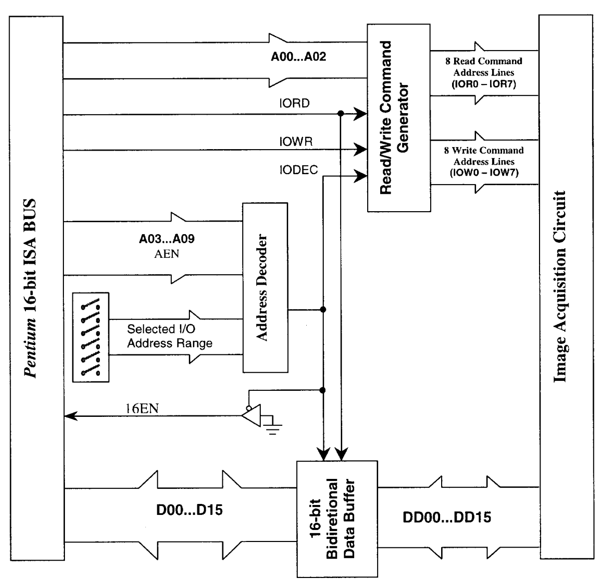

Figure 3. Details of the comunication between the PC bus and the interface circuit.

The analog part of the circuit, including ADC's, comparators and a delay generator is implemented on a standard board with ground plane. The digital part includes address decoding, control and bus communication. It was implemented in another standard board for wire-wrapping circuits. Both standard boards have been designed for this kind of instrumentation development. In the present case they are connected together by a simple bus with power supply, control and data lines, so that a single PC interface card results.

Details of the circuits for address decoding and comunication with the PC bus are shown in Fig. 3. The I/O address established in a DIP switch is compared with an address command from the PC. The result of this comparison enables the transmission of data, address and command lines between the interface circuit and the PC bus. Fig. 4 is a picture of the whole device, including analog and digital circuits.

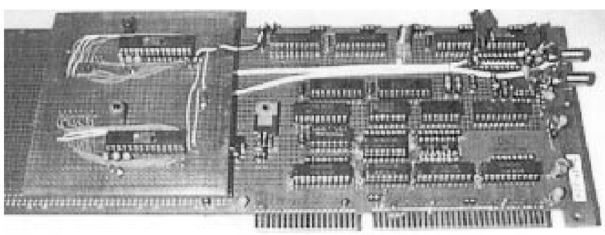

Figure 4.Top view of the implemented device.

III Software Description

The main task for the software code is to check the EOC flag bit provided by the ADC's. When this flag flips to the true state, the twelve bits of each ADC are read from the card to the PC and the flag bit is reset. Since at most 10 bits of each ADC are effectively 6 used- so as to limit the required memory size - some bitwise operations are executed on the read data before they are available for histogramming. Most operations are done by use of Assembly routines, in order to get the fastest execution time. The depth of histogramming bins is a two bytes word, thus allowing up to 2^{16} event counts per bin.

The image display and other programmable facilities such as image size (256×256, 512×512, 1024×1024), ASCII or binary data saving, acquisition time interval etc. are made available by code prepared in the Delphi 3.2 programming environment. Two operation modes are presently allowed by the program. In the first one, the image acquisition may be interrupted at any time by the user. This is a slower mode, since some acquisition time is spent by the program in order to monitor the 'stop' request . A maximum acquisition rate of 1.6×10^5 events per seconds has been measured for this mode, in a PC machine running with Pentium 233 MHz microprocessor. In the second mode, a total number of events is preset by the user, and the program stops acquisition after this number of events has been reached. In this case, the highest observed acquisition rate under Pentium 233 Mhz microprocessor was 3.6×10^5 events per second.

The use of the interface may be enhanced in several aspects by software upgrades. As an example, data acquisition programming may be tuned to specific features of a given application (x-ray imaging, particle detection, diffraction patterns or any other based on two parameters acquisition). On the other hand, software programming may also provide on-line or off-line image treatment (homogeneity corrections, background suppression, coordinates conversion, filtering, etc.).

IV Results

IV.1 Characterization Results

Since the operation of the interface relies on the speed of the presently available microprocessors running in PC's, our first concern was to measure the fastest possible data acquisition rate. In order to measure this rate, X and Y pulses from a pulse generator were input to the interface at different frequencies. Then the measured rate was compared to the true input rate. Fig. 5 shows the results of these measurements for the slow and fast operation modes described in ?3. Highest speed for data acquisitiori is around 1.6×10^5 events per second in the slow mode, and 3.6×10^5 events per second in the fast mode.

Other important characterization measurements such as differential non-linearity, integral non-linearity and resolution are related to the quality of the used ADC's. It has been checked that these agree with information available on the component data-sheet. On the other hand, in case other ADC's have to be used for a particular reason, they may be easily changed in the analog part of the circuit.

As a test for the effective performance of the interface, we have measured Lissajous patterns obtained from two sine wave generators. In this case, two sine waves of different frequencies were sent to the interface inputs, and an external signal of frequency much higher than the sine waves frequencies was used as a trigger to the ADC's. This assured that the patterns were randomly sampled. Fig. 6 shows some of the measured Lissajous patterns. It must be noted that, since the frequencies of the sine waves could not be exactly matched, these patterns were in fact slowly varying in time, so that the image acquisition had to be fast enough to provide 'single shots' of the varying patterns.

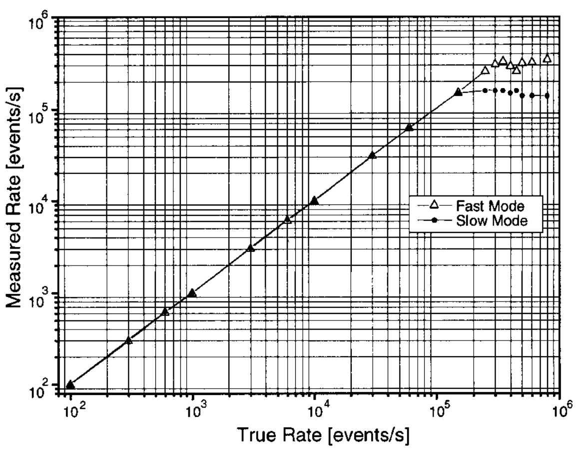

Figure 5. Acquisition rate measurement results.

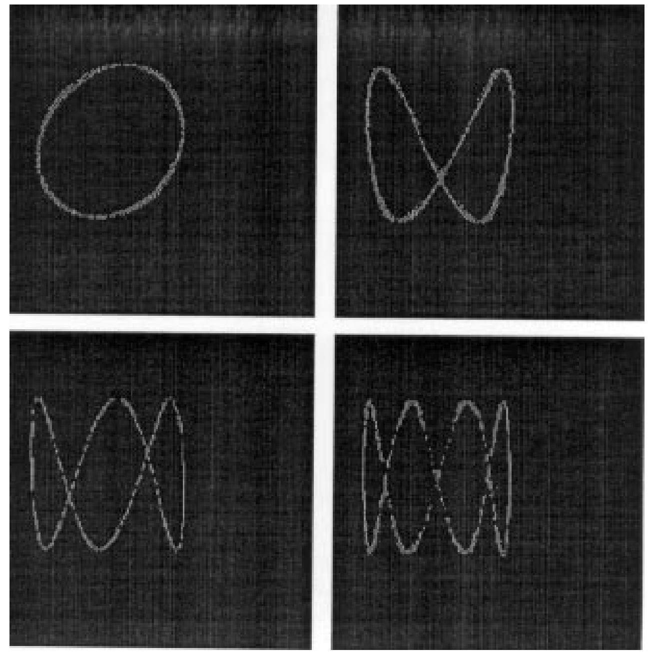

Figure 6. Examples of Lissajous patterns scanned by the image acquisition interface. Sine waves frequencies are multiples of I KHz, while the sampling rate frequency provided by the externnal trigger is 360 KHz.

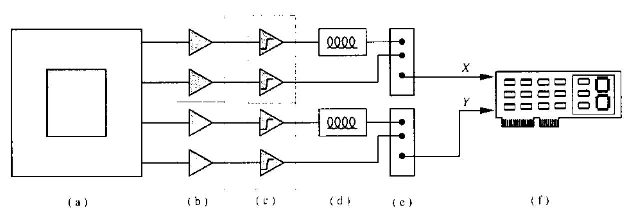

Figure 7. X-ray detection system block diagram including detector (a), pre-amplifiers (b), discriminators (c), delay generators (d), time-to-amplitude converters (e) and the image acquisition interface (f).

IV.2 X-ray Detection

In a two-dimensional position sensitive detector recently developed [9], the position coordinates of an absorbed x-ray photon are directly related to the travelling time of electric pulses produced by gas ionization through a delay line After pre-amplification and discrimination, the travelling time is associated to the amplitude of a signal, by use of time- to-amplitude converters. Delay modules are introduced before the time-to-amplitude converters, in order to avoid negative time interval measurements. Finally, two signals are available whose amplitude correspond to the X and Y coordinates of the absorbed photon. Fig. 7 illustrates the whole detection system.

By sending these signals to the interface input, it is possible to acquire the x-ray image. The data acquisition rate obtained with the interface makes this system competitive for many x-ray imaging applications. As an example, Fig. 8 shows a Laue diffraction image obtained from a powder sample illuminated with Cu-Kα x-ray tube generator. The spatial resolution is close to I mm over an 80 mm $\times$ 80 mm input window. It includes of course the resolution of all the modules composing the system, from the detector to the image acquisition interface. Fig. 9 was obtained by illuminating the detector with a homogeneous and isotropic ^{55}Fe x-ray source through a mask containing the letters "L S D" in lead tape. These letters stand for *Laboratório de Sistemas de Detecção.* This figure illustrates both the detector's homogeneity and spatial resolution.

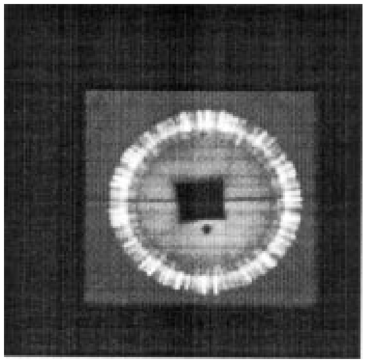

Figure 8. Laue diffraction pattern for a polycrystaline powder sample. Dark region in the center is the beam stopper mask shadow.

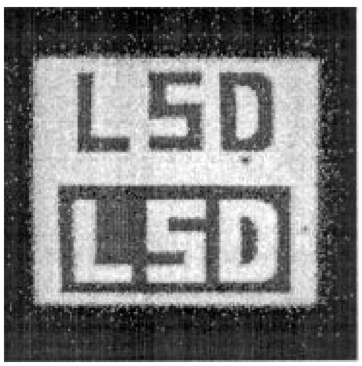

Figure 9. Image obtained by illumination of the detector with an ^{55}Fe x-ray source, through a lead tape mask containing the letters L, S, and D.]

V Conclusion

The developed image acquisition interface takes benefit of the high speed of microprocessors presently available in microcomputers. It is therefore of very low cost, shlce it does not a dedicated processor. Besides, it is also simple from the electronic circuit point of view. The obtained results indicate that it may find applicability in different fields of activity requiring moderately fast image acquisition. A prototype of the interface is presently used in laboratory.

Acknowledgements

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References

1. *AccuSpec System for IBM PC or compatibles.* Nuclear Data Systems. Canberra Nuclear Products Group (1990).
2. *Spectrum ACE^{TM} MCA,* model 916A MCB. Manufactured by EG&G Ortec. USA.
3. *Series II Personnal Computer Analyser.* Oxford Instruments Inc. Nuclear Measurements Group (1993).
4. *MPA/PC Personal Computer Based Multiparameter System.* Canberra Industries, Inc. U.S.A. (1990).
5. *The HCI-PC Board.* Manufactured by HECUS, Dipl. Ing. Mio & Leingartner OEG. Austria (1996).
6. G. B. Fraguas et al., Proc. 17th National Meeting on Condensed Matter Physics, Caxambu/Brazil (1994).
7. C.J. Boulin, R. Kempf, A. Gabriel, M.H.J. Koch, *Data acquisition systems for linear and area X-ray detectors using delay line readout*, Nucl. Instr. and Meth. A**269**, 312 (1988).
8. A.F. Barbosa, C. Boulin, A Gabriel, F. Golding, P. Leyendecker and C. Riekel, *A VME based data acquisition system for a 2D-gasfilled detector*, Nucl. Instr. and Meth. A**302**, 489 (1991).
9. A.F. Barbosa, *Use of a multilayer printed circuit board as the position sensing electrode in a MWPC,* Nucl. Instr. and Math. A**371**, 368 (1996).