A PC104 Multiprocessor DSP System for Radiation Spectroscopy Applications

J. Basílio Simões, João Cardoso, Nuno Cruz, and Carlos M. B. A. Correia
Instrumentation Center, Physics Department of the University of Coimbra
P-3004 516 Coimbra – PORTUGAL

Abstract

A multiprocessor DSP system hosted in a PC104 Windows CE industrial PC is presented. It is based on a master floating point Digital Signal Processor (DSP), a scalable number of slave DSPs and, special purpose trigger, pulse locator and data routing digital circuits. Although this architecture, as well as the data acquisition block, has been optimized to accommodate high throughput pulse rates in nuclear spectroscopy applications, its generality allows for many other signal processing and control applications to be implemented.

1. Introduction

Radiation spectroscopy has been around playing an important role in a number of scientific, industrial, environmental, and medical situations since the early 50's. The great applicability of this non-destructive technique outcomes from the fact that the radiation spectrum is an intrisic property of each element. As a consequence, the radiation spectrum of a sample can be used to simultaneously identify several of their constituent elements even if they are present in very low concentrations.

In the example of figure 1 the composition of a piece of pottery is identified from its γ-ray spectrum. The importance of energy resolution in radiation spectroscopy is clearly revealed in this figure by comparing the spectra obtained using a NaI scintilator detector and an high-resolution germanium detector.

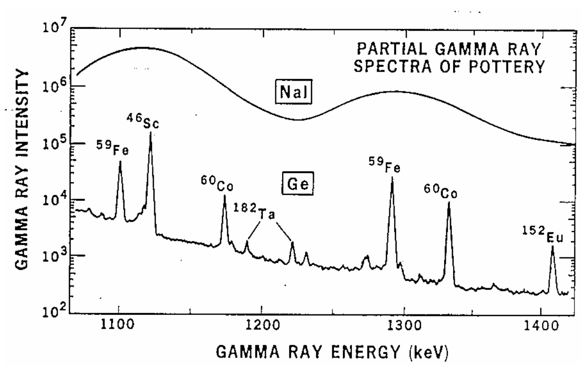

Figure 1: γ-ray spectra of pottery [1]

The function of a spectrometry system consists of converting the electrical-charge pulses originated at the output of the radiation detector into voltage pulses and, afterwards, obtaining their amplitude distribution function as accurately as possible. This task has been accomplished, for decades, using a three stage almost all-analog system, schematically represented in figure 2: preamplifier, pulse shape amplifier, and the Multichannel Analyzer (MCA) that divides the amplitude space (generally associated to energy) in a number of equally spaced intervals, usually referred to as channels. The number of the channels the system is capable to differentiate represents its energy resolution.

In this architecture the MCA is usually the critical equipment concerning the overall performance of the system. It is mainly composed of the central peak stretcher with its companion linear gate, baseline restorer, current sources for discharging the store capacitor, and the Analog to Digital Converter (ADC) and memory to convert pulse-height to the digital domain and build-up the histogram. Other blocks, as discriminators, pileup rejectors, or peak stabilizers, can be optionally found.

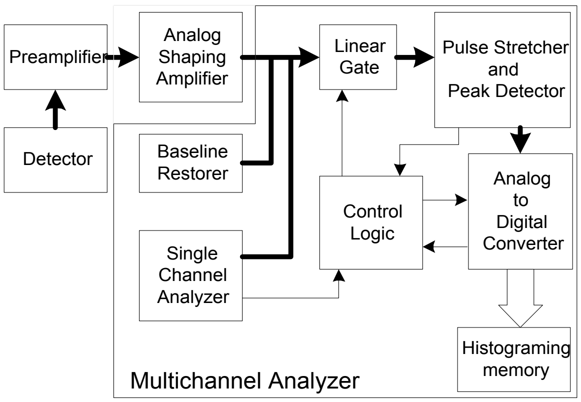

Figure 2: Architecture of the classical spectrometer

The performance characteristics of the MCA as its number of channels, linearity, and dead time, are, in turn, normally dependent on the specifications of the ADC. Thus, the technological evolution undertaken by MCAs has naturally followed that of ADCs. The first MCAs were based on Wilkinson type ADCs. Thanks to their excellent linearity they are still used nowadays in systems with 4k or 8k channels using clock frequencies up to 400 MHz. However, conversion time is the main drawback of this kind of ADC which leads to long dead time MCAs.

The successive approximation type ADC is much faster but has poor linearity. Its popularity in MCA applications has only been possible with the use of the sliding scale method to improve its linearity [2].

Flash type ADCs provide a yet faster analog-to-digital conversion but, at the current levels of integration, the number of channels and linearity exhibited by them are still incompatible with their straightforward application in the conventional MCA architecture. However, it was the outcome of flash ADCs with conversion times of a few tens of nanoseconds that finally triggered, in the 90's, architectural changes in pulse spectrometry systems allowing its evolution towards the digital domain.

In the new devised design, figure 3, the conventional analog front end is replaced by a digital pulse processor that computes pulse-height out from the data sampled by a fast high-resolution ADC.

The advantages of this method have been widely recognized. In fact, besides avoiding the non-linearities and instabilities of the analog front end, this digital approach makes it possible to synthesize the theoretical optimum weighting function, taking in account the noise that is effectively present in the experimental set-up, and thus obtain the best energy resolution [3]. Moreover, physical effects such as pile-up, ballistic deficit and charge trapping and recombination can now be corrected or eliminated at the processing level [4]-[5].

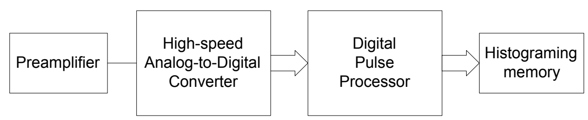

Figure 3: Digital pulse processing spectrometer

Although the most versatile and straightforward way to implement the digital pulse processor is through a software routine, the large computation time required by this approach has always limited its practical use. Then, to comply with the desired high throughput rates, some hardware or mixed analog-digital pulse processor circuits have been recently developed sacrificing some versatility and resolution [6], [7]. This is necessarily a transitory situation since the development of Technology is continuously making available more powerful DSPs running at increasingly higher clock frequencies. Therefore, based on the current expectations, we can guess with great confidence that in the next decade a software based digital pulse processing spectrometer will be capable of higher throughput rates than the current state-of-art analog pulse height analyzers (PHAs). While such a powerful DSP is not available other solutions must be tried as the multiprocessor architecture here presented.

2. The multi-DSP architecture

The developed multiprocessor pulse spectrometry architecture is based on a master unit that connects to a scalable number of peripheral slave units (SU) through the communications, pulse transfer and control buses. The master unit contains, in addition to the DSP, a trigger and pulse locator unit (TPLU), a bus control unit (BCU) and a very simplified analog front end.

The master DSP supervises the digitized pulse data transfers to the SUs, collects the processed pulse parameters from them and builds up the energy spectrum of the incoming pulses. It also accommodates the interface routines with the host processor and is responsible for the download of the program code to the slave DSPs.

The analog front end is reduced to a linear amplifier state, a trigger unit and a fast and high-resolution digitizing block. Its digital output is temporarily stored in first-in-first-out (FIFO) memories that function as the first of several levels of pulse buffering implemented in the system, using both hardware and software mechanisms, and that contribute to the very reduced dead time of the system.

The input signal is continuously digitized and transferred, through the pulse transfer bus, to the local FIFO of the selected SU. Each SU is identified by a different address located in the slave control unit (SCU). When the FIFO of the selected SU gets full, a SU_busy signal is promptly issued by the SCU. As an immediate consequence, the BCU selects, through the control bus, the next free SU and interrupts the master DSP signalizing the occurrence.

If the number of SUs is large enough to assure that at least one of them is always available to receive the digitized input stream, a virtual zero dead time spectrometry system can be obtained.

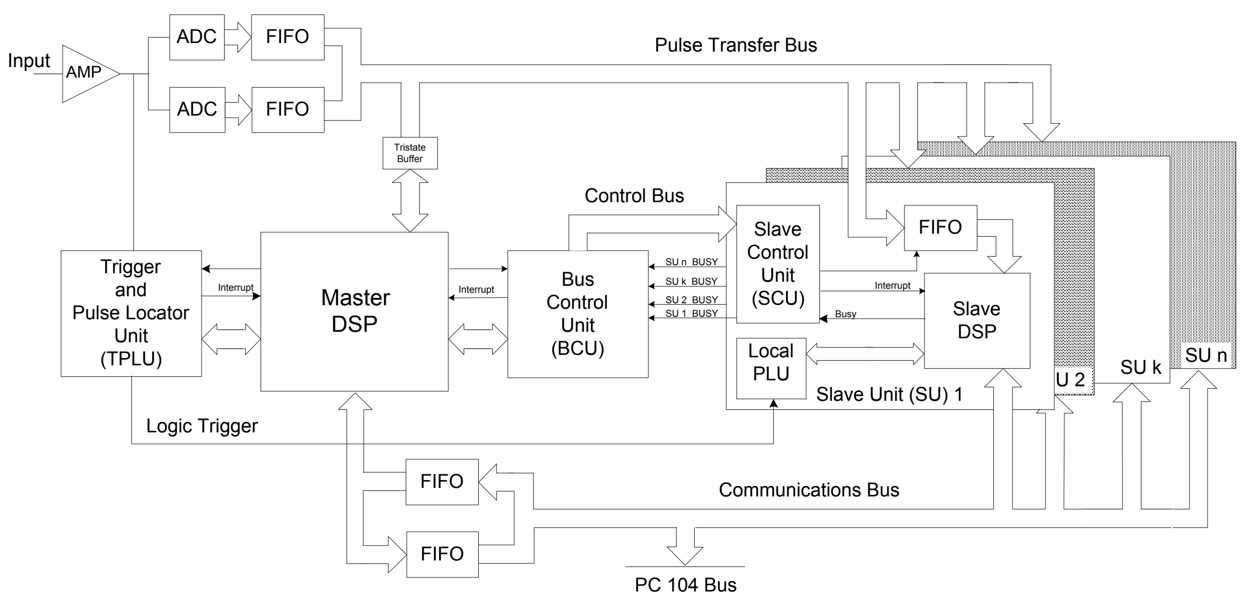

Figure 4: Architecture of the scalable multiprocessor digital pulse processing system

The basic concepts of this architecture have been previously tested using the ubiquitous ISA bus, the low-cost floating point Texas Instruments TMS320C31 DSPs and an 80 MSPS, 12-bit, interleaved digitizing block with two Burr-Brown ADS800 ADCs [8]-[9]. The refined version now presented is hosted in the industry standard PC104 bus and has a simplified logic control that has been attained by the inclusion of a local PLU in each slave unit. Other significant improvement comes from the use of components very recently released to the market like the new 14-bit 65MSPS IF sampling A/D converters, voltage controlled amplifiers, high density SRAMs and FIFOs and MACH 5 value plus family.

Although inspired by the needs of the radiation spectroscopy applications, the intrisic generality of the presented system as well as a few added features (like the association of an high speed D/A channel to each slave DSP and the use of a connector allowing for piggy-back customized analog front ends) open to it the possibility of being used in many other signal processing and control applications.

3. Real-time operating system

To accomplish the need for continuous and uninterrupted operation as well as the bounded response time constraints characteristics of real time systems, the software running in all the DSPs was designed to comply with the standard Posix.4 [10].

The software interface affects how users will experience a system or product more than anything else. So, it is very important to have a good user interface design, with visual and functional consistency. Users should be able to visualize and interact with data without having to think about applications, just concentrating on their tasks. For this reason a user-friendly operating system was an absolute need. As the presented system requires a real-time operating system (RTOS) the choice was for Microsoft® Windows® CE.

Windows® CE is a RTOS based on industry standards designed for 32-bit embedded systems. It fulfills the need for a small operating system that works for a broad range of products. Its modularity allows for the design of embedded system platforms using the minimum set of software modules and components needed to support the system requirements. This minimizes the memory footprint and maximizes the performance of the operating system.

Other advantadge of Windows CE is its ability to support many kind of hardware peripherals and devices. In our system special attention was devoted to the touch panel, Ethernet, as well as the storage device support. The creation of standard drivers to the application specific developed hardware was also taken in account, which is made possible through Windows CE's Device Driver model.

The radiation spectroscopy application software was developed under a client/server architecture. The server application runs in the embedded system, while the client application may run in the same machine (when the purpose is to have a portable system that allows for the visualization of the acquired data on site) or over an Ethernet connection in a remote computer running Windows 95/98/NT (Internet can be used if bandwidth is enough).

The main purpose of the server program is to act as a bridge between the digital pulse processor board and the client program. At startup it initializes the board by downloading the TMS COFF files through the communication bus to the DSPs. It establishes a communication channel to the DSP and waits for a client connection. When a client program connects, it will wait for commands sent by the client to execute.

The client program is the most visible part of the fully integrated system. This is the program that the user runs to operate the system. All the commands like start/stop acquisition, reset board and definition of acquisition parameters are included in this program whose main window is fully dedicated to the display of the acquired spectrum.

The client program may run in several platforms. Since the communication protocol used is standard TCP-IP, which is available in most operating systems, it is very simple to port this program to platforms like UNIX, VMS or MacOS.

4. Conclusions

Recent developments with fast and precise ADCs and inexpensive and powerful DSPs have brought digital signal processing systems within the realm of practicality. This is the case of the presented scalable multiprocessor DSP system, hosted in a PC104 Windows CE industrial PC, that is based on an architecture optimized to accommodate high throughput pulse rates in radiation spectroscopy applications.

As a concluding remark, it is interesting to notice the parallelism between the described migration from analog to digital in the architecture of radiation spectroscopy systems that occurred in the early 90's, with all the mentioned advantages, and what we are currently observing in the communications domain. In fact, the dramatic improvement in the performance of A/D converters, materialized by the recent outcome of IF sampling ADCs, are enabling the digitization of the entire spectrum at one time and allowing for the design of all-digital radio receivers with the same kind of advantages above mentioned to the spectrometry systems: reduced front-end filtering requirements, elimination of the factory adjustments of analog components, reduced assembling costs, enabling software configurable solutions, etc.. This fact certainly make us devise the application of the presented multi-DSP system far beyond the radiation spectroscopy field.

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