Computer-Based Digital Signal Processing for Nuclear Scintillator Detectors

M. A. Ashour, A. M. Abo Shosha
NCRRT, AEA
P.O.B. 29, Nasr City, Cairo, Egypt. Fax: ++202- 2749298

Abstract

This article addresses a digital signal processing (DSP) computer-based technique for nuclear scintillation detector signals with an exponential decay. The main objective of this framework is to identify the characteristics of acquired signals robustly; this can be achieved by transferring the signal analysis environment from the random signal domain (sample space) to the deterministic domain (discrete time domain) using digital manipulation techniques. The system, under study, consists of two major parts. The first part is the high performance data acquisition system (DAQ), which depends mainly upon a digital multi-channel analyser. This analyser is interfaced with the host computer through a general purpose interface board (GPIB) Ver. IEEE 488.2. Furthermore, a graphical user interface (GUI) has been developed for this purpose, using the graphical programming facilities. The second of this system is the DSP software algorithm, which analyzes, these data to estimate the main characteristics of acquired signals e.g.; the amplitude, the pulse count, the pulse width, decay factor, and the arrival time.

I. Introduction.

The nuclear systems are complicated and large scaled systems. To achieve the robustness, DSP and DAQ processes of these systems must fulfil the following requirements:

1) High storage capacity and high speed measurements: Suppose that, the main target of the DSP & data acquisition system is the measurement of certain nuclear events or signals that acquired from detectors. These events influx with high rates & density toward the detectors so, the flux of data demands a high capacity storage to receive these huge amount of information in a finite short time. This means high speed (μ s or *ns*) DAQ system to avoid data loss.

2) Highly precise and sensitive systems. This is required to get the right decision during the operation, control, diagnosis, or the scientific analysis of these experimental results.

3) Flexibility & Reliability systems. The research work and laboratory activities require reliable and multi-task systems, capable of supporting a wide range of application requirements easily.

Recently different computer-based techniques have been used to nuclear events measurements e. g.; programmable PCI interface [1-5], fast CAMAC [6], CAMAC and VXIBUS [7] and other computer-based systems for nuclear applications [8-9]. The first part of this study is the implementation DAQ system. The DAQ depends mainly on the multi channel analyzer with a sampling rate up to 2 Gega sample per second (2GS/S) and 16 acquisition channels . The data acquisition bus is used to control the interface process between the host computer and the multi channel scope. The signal sources, which used throughout this work, are generated using one of the following three methods; 1) software simulator of scintillator detector signals, 2) electronic signal simulator, designed to generate scintillator detector alike signals, or 3) real signals of the scintillator detector in experimental measurements of the radioactivity for different sources ($_{60}$Co, $_{136}$Cs). The software integration between graphical programming and the low level dynamic link libraries is used to drive the DAQ and the DSP algorithm. In section (II), the DAQ system is illustrated. Section (III) explains the realisation of the DSP algorithm. In section (IV) the conclusion and the discussion are outlined.

II. The DAQ system

The ANSI/IEEE Standard 488.1-1987, also is known as GPIB [10], describes a standard interface for communication between instruments and controllers from various vendors. It contains information about electrical, mechanical, and functional specifications. The GPIB is a digital, 8-bit parallel communications interface with data transfer rates 1/5 Mbytes/s and above, using a 3-wire handshake. The bus supports one system controller, usually a computer, and up to 14 additional instruments. The ANSI/IEEE Standard 488.2-1992 extends IEEE 488.1 by defining a bus communication protocol, a common set of data codes and formats, and generic set of common device commands. The GPIB devices can be Talkers, Listeners, or controllers. The analyser has its special commands groups that enable the user to control all analyser jobs using the GPIB, these groups are; acquisition commands group, calibration and diagnostic group, monitoring group , and filing system group. In general the device frame commands can be divided into two major types. The first is the query type, these commands are used to ask the device about a certain parameter and the device returns the answer to the controller. The second type is the non-query commands that are used to control a certain device or to transfer data to this device. Some commands can play the two roles query and non query command types. To avoid the conflict that can occur due to controlling the device from the control front panel and the remote host GPIB at the same time, almost all GPIB devices supports the locked operation mode. During the locked operation mode the device can be controlled using the host GPIB only. Another important parameter must be taken in consideration, is the device time out, the time required to receive the device reply. Each command for each device has its own time out. The time out can be ms or seconds according to the command and the device

In general the applied GPIB based DAQ protocol for the analyser, shown in fig.(1), obeys the following sequence; **1)** Scanning the bus for the on line devices and reading the device name and its corresponding address. **2)** Defining of the devices time out. **3)** Locking the remote devices to prevent the misuse of the control front panel. **4)** Clearing the GPIB board and the attached devices. **5)** Initialisation of the measurement parameters such as; x,y-axis division units, groups, wave forms, threshold value, wave form record length,...etc. **6)** Determine the measurement tasks (Values measurements, wave acquiring, ...etc.) **7)** Request the data from the device. **8)** Read the data from the device. **9)** Storing the data files. **10)** Clean up cycle . **11)** Unlock the device to enable the front panel control.

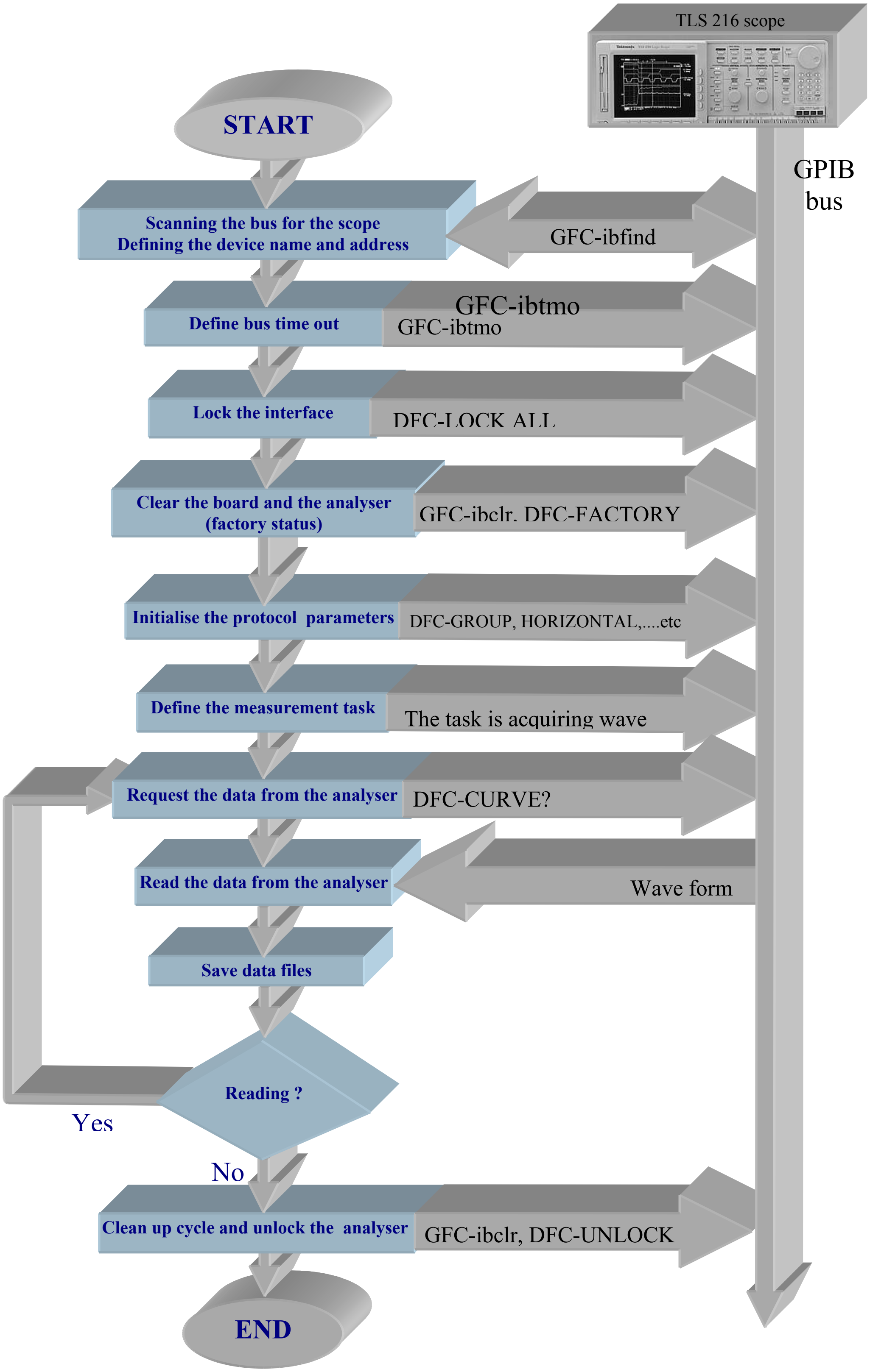

Figure (1) GPIB based data acquisition system.

Note:
DFC→Device Frame Command, GFC→GPIB Frame Command

The GPIB-based DAQ system is shown in figure (2,3). In figure (2), the first channel of the scope (2.1) is connected the output of the scintillator (2.3) to measure the output signal due to using radioactive source. The scintillator detector is connected to High voltage source (2.2) and Vcc power supply (2.4). In figure (3), The controller (the host computer system) (3.2) is interfaced with the scope (3.1) using the GPIB. The channels of the scope are connected to the output of the pulse generator (3.3).

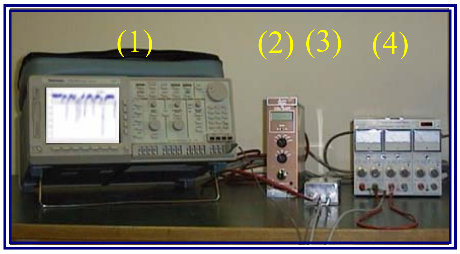

Figure (2) The TLS 216 is attached with the scintillator detector

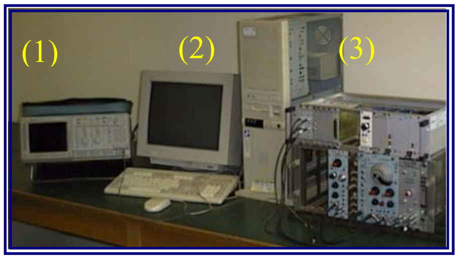

Figure (3) the system is attached with the pulse generator and the TLS 216 scope

The presented DAQ system can acquire the data as instantaneous measurements, or wave forms. Figure (4) shows a typical wave form, that is acquired by the DAQ system. The measured signal is the output of the scintillator detector due to a radioactive source.

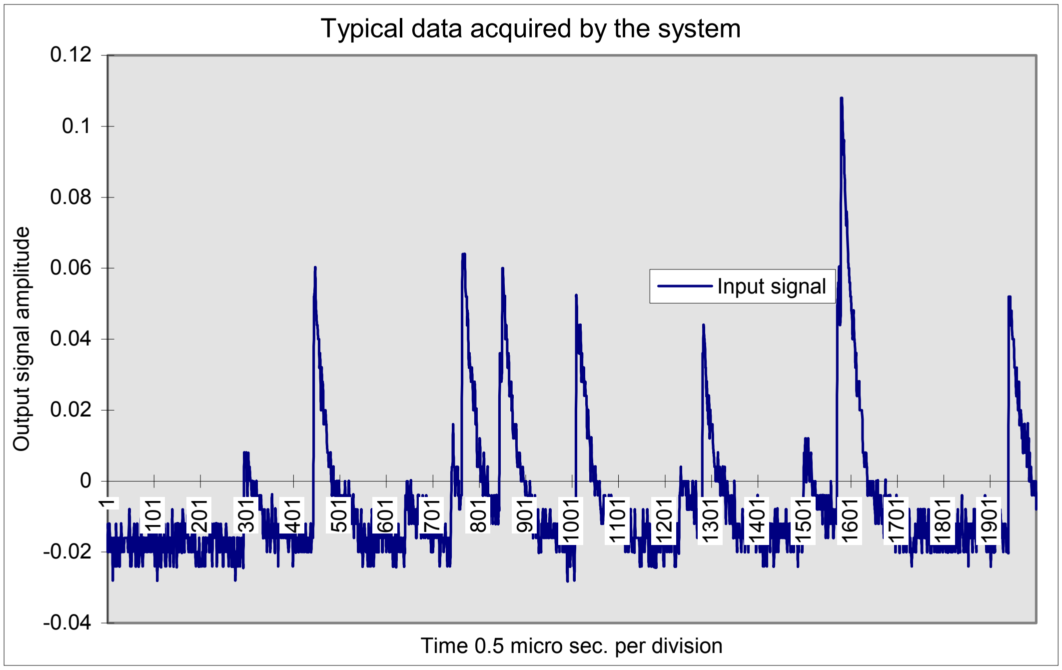

Figure (4) A typical wave form acquired by the data acquisition system of the scintillator output.

The pulses that are acquired by the scintillator detector have a different height depend on the energy of the event that hits the detector. The exponential damping of the pulse is caused by the internal architecture of the pre-amplifier circuits. Also, The pulse generator figure (3) can be used to simulate the output signal of the scintillator detectors with single or double pulses. Figure (5,6) shows the output of the pulse generator for double and single pulses. The pulse generator can define the delay between pulses, the pulses amplitude, adding or subtracting the signals, and the frequency.

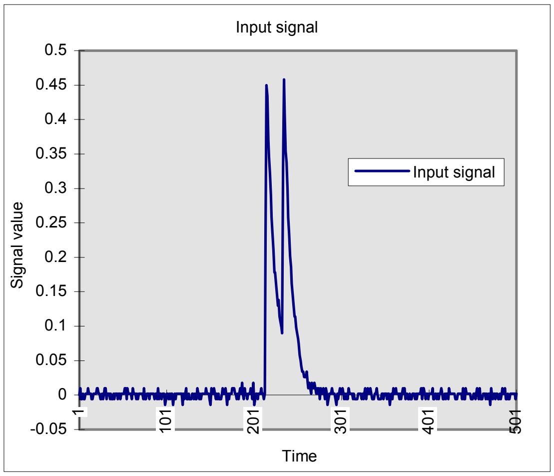

Figure (5) The output of the pulse generator for the double pulse mode.

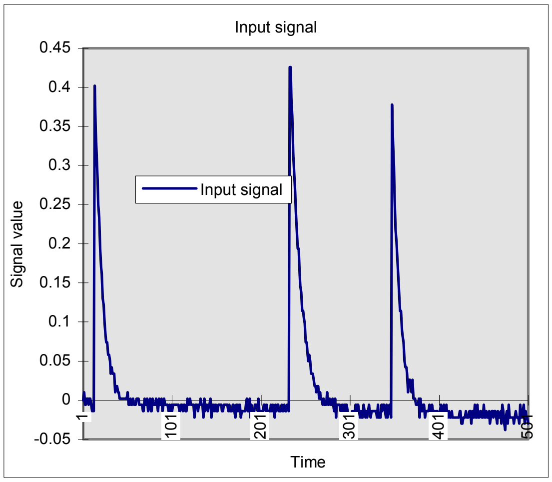

Figure (6) The output of the pulse generator for single pulse mode.

III. DSP of Scintillator Detector Signals

III. 1 The Basic DSP Algorithm

The main objective of the DSP algorithm is to transfer the system from random domain (sample space) to deterministic domain (discrete time domain) to identify the main characteristics of acquired signals robustly. The DSP analysis of nuclear events can be carried out using software programming or hardware implementation for very high speed applications. In this study the software programming is used to apply the DSP algorithm. The main diagram of this algorithm is shown in figure (7) [12].

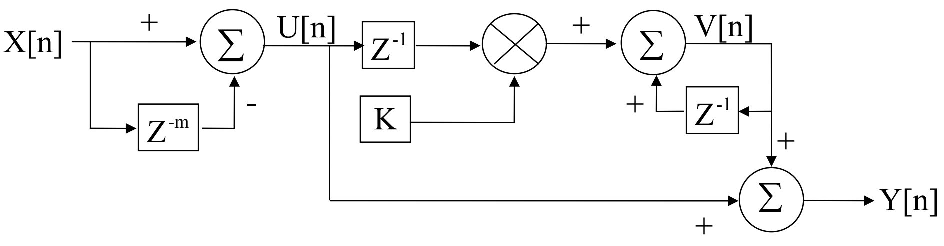

Figure (7) DSP algorithm of the of the nuclear event signals.

The system input signal X[n] is the output of the scintillator detector under the influence of a radioactive source. The subtractor output is U[n], this is the subtraction of delayed signal X[n-m] from the original signal X[n], and m is the pulse width from rise time till the end of the signal. The output of the multiplier W[n] is the product of multiplying the signal U[n] by the factor K, which is time dependent and will be used later in optimizing and fitting of the DSP results. The accumulator output is V[n] and the output of the algorithm Y[n] is the summation of the accumulator output and subtractor output. The symbol Z^{-1} is the back shift operator whereas $Z^{-1}X[n]=X[n-1]$. The multiplication factor K is a constant value that depends on the timing constant of the damped pulse. This algorithm can be formulated simply by the following representation.

U[n]=X[n]-X[n-m] .... Subtractor output
V[n]= kU[n-1]+V[n-1] .... Accumulator output.
Y[n]=U[n]+V[n] .... Algorithm output.

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At first, let us simulate all the DSP modules using the software programming. The detector pulse will be simulated by exponentially damping signal with a definite height, width, and damping time constant. The input signal X[n], the subtractor output U[n], the accumulator output V[n], and the algorithm output Y[n] are shown in figure (8). There is a great difference between the ideal simulation world and the actual real one. Taking a lock over the simulation results we can notice that; **1)** Pulses are repeated with constant frequency. **2)** All the pulses have the same amplitude. **3)** The system is noise free (the algorithm input, the internal signals, and the algorithm output). **4)** No double or treble pulses. The difference between the simulation and the real signals can be noticed from the comparison between the simulation signal figure (8) and the real signal figure (4). The second step is the realisation of the algorithm using special pulse generator output. In this case, the output of the pulse generator will be used instead of the actual pulse of the scintillator detector under the effect of using radioactive source. This is considered as transient stage to test the DSP algorithm performance and the data acquisition system.

3. 2 Optimisation of DSP Parameters

The main targets of the optimisation process are; **1)** Minimisation of Root Mean Square RMS of errors. **2)** Sharpening of shaping frames. The major parameters of the processor are the delay factor (m) and the multiplication factor (K) figure (7). The delay factor determines the length of special buffer FIFO that is used to delay the signal. The optimising of the delay factor increases the precision of the results. The delay factor has a physical meaning that is related to the pulse width. The delay factor equals the number of samples per pulse. The delay factor is calculated by minimising the RMS of errors. The multiplication factor (K) increases the sharpness of digital frames that include the pulses. The suitable value of K can determine the difference between signal, double, and triple pulses. The realisation of the DSP algorithm on the actual measured pulses is shown in figure (9). The algorithm is applied to a real scintillator detector pulses under the influence of the radioactive source. The difference between the realisation and simulation of the DSP algorithm can be noticed by comparing figure (8) and figure (9).

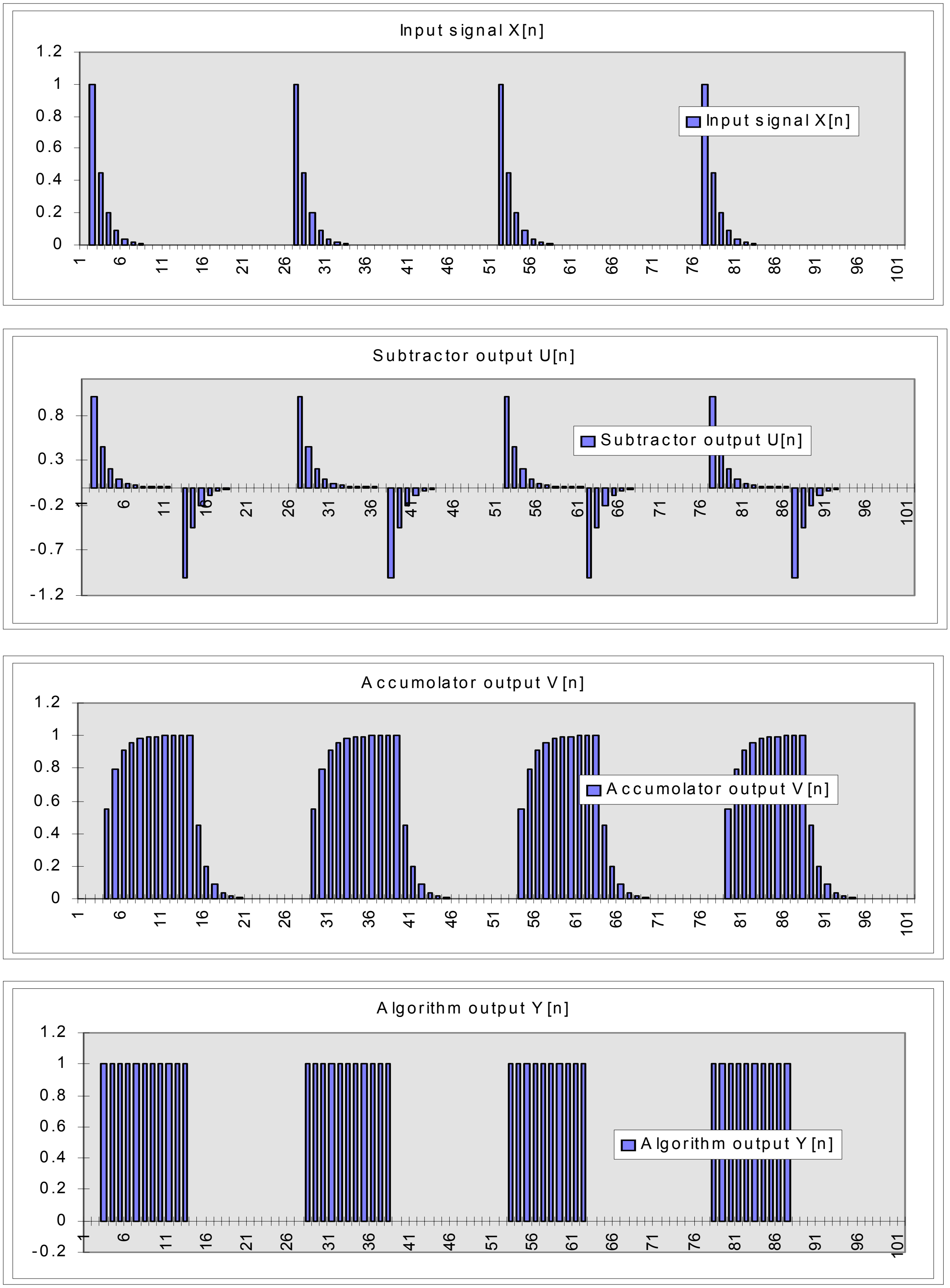

Figure (8) The software simulation of the scintillator detector output X[n] and the algorithm signals U[n], V[n], Y[n].

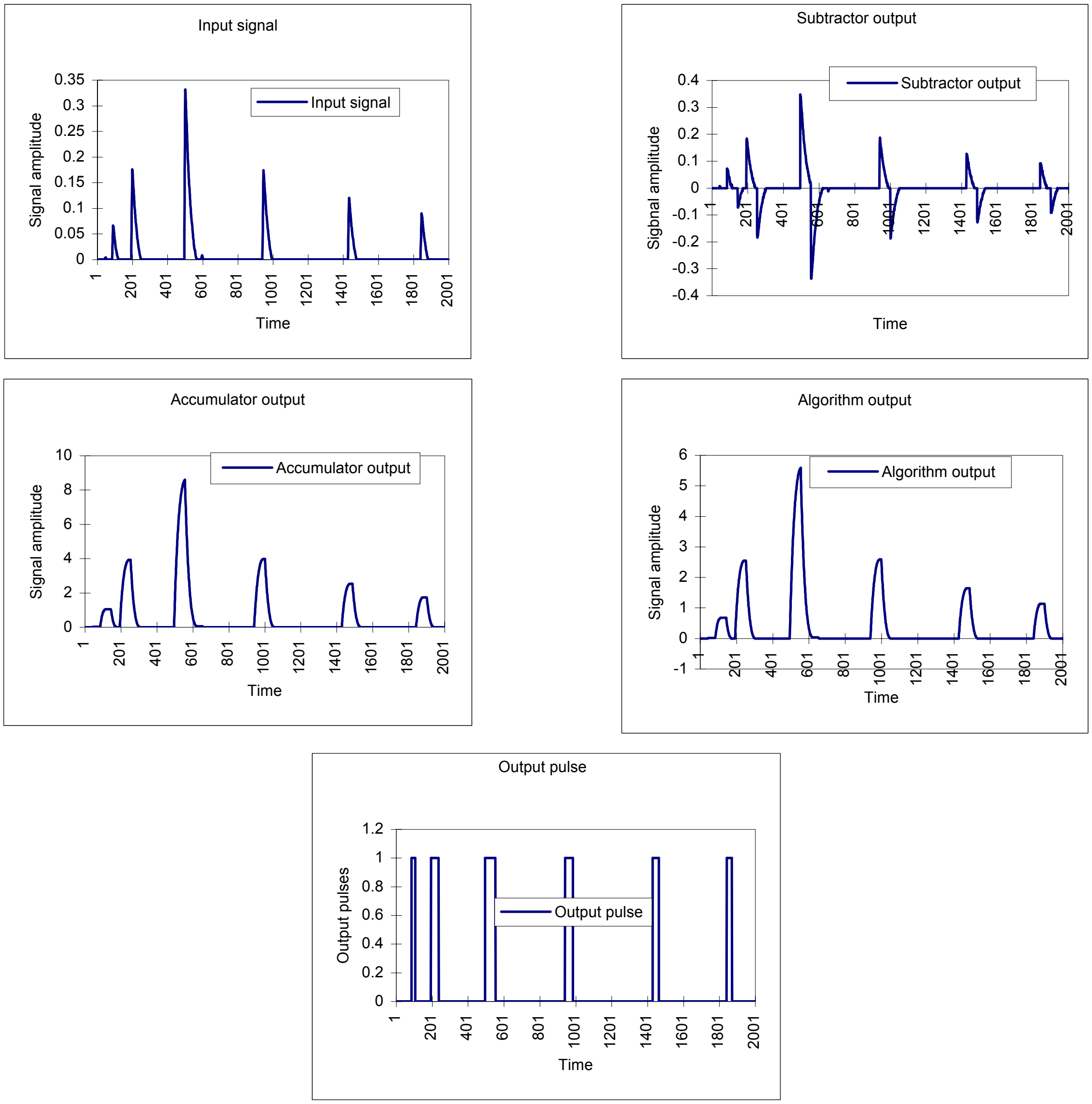

Figure (9) a presentation of the DSP algorithm, the input signal, the subtractor output, the accumulator output, the final Algorithm output, and digitised output pulses.

IV. Conclusion

The GPIB based data acquisition systems offer a considerable solution for the purpose of nuclear signal acquisition. The integration between the GPIB based instruments and the computer-based controller techniques supports researchers with high reliability systems. The applied DSP algorithm can be implemented simply to analyze the acquired data of the DAQ systems. The immigration from the ideal simulation world to the actual realisation needs an intelligent digital processing technique to deal with the measurement noise and this what we have accomplished throughout this framework. The realization of the DSP algorithm, in case of the double or the triple pulses can be achieved with more complexity to analyze these signals. The hardware implementation is another trend which can realise the DSP algorithm in the future work.

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