LA-UR- 09-06289

Approved for public release; distribution is unlimited.

Title: Minimum Functionality Attribute Measurement System-Software Implementation

Author(s): David J. DeSimone, N-1
Jonathan Thron, N-1
Duncan MacArthur, N-1

Intended for: DOE, NA-241

Los Alamos
NATIONAL LABORATORY
EST. 1943

Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the Los Alamos National Security, LLC for the National Nuclear Security Administration of the U.S. Department of Energy under contract DE-AC52-06NA25396. By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.

LA-UR-09-6289

Approved for public release; distribution is unlimited.

Title:	Minimum Functionality Attribute Measurement System-Software Implementation
Author(s):	David J. DeSimone, Jonathan Thron, and Duncan MacArthur Los Alamos National Laboratory
Intended for:	Deliverable to NNSA

Los Alamos NATIONAL LABORATORY EST.1943

Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the Los Alamos National Security, LLC for the National Nuclear Security Administration of the U.S. Department of Energy under contract DE-AC52-06NA25396. By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.

Minimum Functionality Attribute Measurement System-Software Implementation

David J. DeSimone
Jonathan Thron
Duncan MacArthur

October 2009
Los Alamos National Laboratory

Los Alamos National Laboratory
PO Box 1663
Los Alamos, NM 87545

1 OVERVIEW

1.1 The Next-Generation Attribute Measurement System

An attribute measurement system (AMS) is a nondestructive measurement system (e.g., it measures neutron and gamma-ray emissions) that uses information barriers (IBs)[1] to protect sensitive data concerning the nuclear item being measured. A potential use is the measurement of plutonium samples in canisters for treaty verification.

These measurements could be used by a monitoring party to verify declarations made by the host party concerning the contents of a sealed container. Because some of the measurements could involve quantities that the host considers sensitive, the information displayed to the inspectors would be agreed on in advance by both parties so as to show only limited amounts of nonsensitive information (attributes). However, the monitor must have confidence that the displayed attributes are a correct representation of the canister's contents.

The Next-Generation Attribute Measurement System (NG-AMS)[1] incorporates an IB that ensures that no sensitive information is present outside the NG-AMS. This IB includes physical barriers and controls to prevent inadvertent information leakage, as well as a data barrier to control the amount of information that is displayed. The NG-AMS was used to measure three specific attributes of a declared plutonium sample: the plutonium isotopic ratio, the plutonium mass, and the plutonium age (date of last americium separation).

1.2 Implementations

Any measurement system such as the NG-AMS will incorporate hardware (e.g., the detectors and display) and software (e.g., numerical computation) components. In addition, many system functions can be performed either in hardware or software. For the purpose of this paper, we define a software-centric measurement system as digitizing all incoming signals as early as possible and then handling all processing and decision making in software. In contrast, in a hardware-centric system, the conversion to digital information occurs as late as possible. Both the software and hardware components are difficult to authenticate fully.

Although hardware-intensive implementations of an AMS have been constructed,[1] these implementations allow very little flexibility during the troubleshooting phase. Software, with the appropriate hardware (e.g., the neutron- and gamma-detectors themselves), offers flexibility to optimize certain characteristics of the measurement and adapt to changing requirements and negotiated positions. Also, software allows a direct bit-to-bit comparison between copies possessed by the two parties if a "golden copy" is available. Because any AMS will include software elements and choices must be made concerning other elements, this paper will identify strengths and weaknesses of the software-centric approach.

2 NEUTRON MULTIPLICITY CALCULATIONS

2.1 Introduction

The neutron system is used to measure the rate of spontaneous fission in the plutonium item being assayed. Because the spontaneous fission rate for each isotope is known, the mass of plutonium in the item can be determined from the total fission rate, combined with the plutonium isotopic composition fractions from the gamma spectrometry measurements. In the hardware-centric approach used in earlier AMSs, the signals from all of the individual ^{3}He tubes in a neutron multiplicity counter (NMC) were combined into a single-pulse stream and into a hardware shift register used to generate the number of events (singles), coincidences (doubles), and triple coincidences (triples).

Timing information in the form of a time stamp is the only requirement from the NMC. List mode data acquisition for the NMC is one approach that can be used in the 3G-AMS system. The principle of operation is that after each detection event, the time at which the detection happened is sent to the personal computer (PC). The result of the acquisition is a (possibly large) "pulse train" file containing all of the information for each individual detection event (typically time and channel number).

The pulse train can then be analyzed during or after the acquisition with processing software that simulates the operation of a shift register [pre-delay, opening of the real and accidental (R+A) gate, scaler counting, delayed gate for accidentals, and storage of multiplicity distributions] and to compute all of the physical parameters needed: singles, doubles, triples, and associated uncertainty. This approach has been done by J. Bagi et al.[2] The pulse train can be analyzed with many different input parameters from a single measurement. List mode data acquisition for the NMC is one approach that could be used in the 3G-AMS system.

2.2 Possible Implementation

The Multi Event Data Acquisition System (MEDAS) plug-in card developed by CeSigma can acquire logic signals with associated time stamps. MEDAS can run on MS-DOS, Windows 3.2,95,98, and XP, NT, and Linux operating systems. A configuration and acquisition program is available in LabView that will run under Windows or Linux. A high-level C/C++ library is also available. The system can date and count physical events with an input frequency up to 10 MHz simultaneously on 32 inputs with an accuracy of 25 ns. The available memory will determine the capacity of recording. A count rate at 150,000 counts/s for 100 s will create a binary file of about 100 Mb. The binary file can be converted to American Standard Code for Information Interchange (ASCII) for further processing. A software package called the Treatment of Dated pulses coming from Neutron Emitters (TRIDEN) developed by IRSN to process the digital pulse train from MEDAS and determine count rates for singles, doubles and triples can be used. Other software packages such as C/C++ can be used to write programs to compute singles, doubles, and triples.

2.3 Discussion

Pulse time stamping offers the ability to change parameters during the troubleshooting phase in software relatively easily to optimize the system. With a classical mode of acquisition based on a shift register, where the signals from the individual ^{3}He tube are combined before processing, it will be much more time consuming to obtain comparable information about the quality of the result.

Each ^{3}He tube has an individual cable that is connected to the list mode device; if an adversary were to pick a cable at random and add an extra signal, appropriate software and other features that would not reveal sensitive information could show that one particular tube had an extra signal, and the computer would know that something was wrong, especially if the cable that was chosen came from a ^{3}He tube on the outer ring of the multiplicity counter where the count rate should be lower. A computer program could be incorporated into the AMS to search for this type of anomaly.

Because each ^{3}He tube is connected to the list mode data acquisition system, a program could be written to look at the state of health of each detector; when a detector or one of its components failed, a light could come on indicating that something was wrong. This process would be difficult or impossible to accomplish with a conventional shift register system.

In list mode, there are numerous cables from the detector to the list mode data acquisition device and there is also a large amount of data to process and storage devices that are needed. A device to combine these signals and/or derandomization circuits could be added, but it would increase the amount of hardware.

3 GAMMA-RAY CALCULATIONS

3.1 Introduction

The AMS will use a high-purity germanium (HPGe) detector to acquire pulse height information (energy information) through appropriate hardware and software to collect a spectrum of the item behind the information barrier. With the appropriate software, determinations will be made of the ^{240}Pu/^{239}Pu ratios, as well as the age of the item. A software package such as FRAM can be used for this analysis.

A software-centric approach to digitizing the gamma-ray signals is to use a waveform digitizer. In an HPGe spectrometry system, digital signal processing (DSP) replaces the shaping amplifier, correction circuits, and analog-to-digital converter (ADC) with a single digital system that processes the sampled waveform from the preamplifier with a variety of mathematical algorithms. DSP techniques have been used in the field of HPGe detector gamma-ray spectrometry for some time for improved stability and performance over their analog counterparts.

The waveform digitizer is an electronic device that samples the input analog signal at a high rate (compared with the width of the analog pulse) and stores a digital representation of the analog pulse that can be manipulated in software. The quality of the digital representation is dependent on the number of samples per second of the input signal pulse. Certainly, the more samples per second that are acquired, the better the representation and the better the resolution but the more expensive the digitizer becomes.

A wave form digitizer consists of five main components:

1. A measurement section comprising impedance-matching components, preamplifiers, and one or more ADCs. Impedance matching and preamplification allow the input signal to be conditioned to match the voltage range of the ADC best so that the maximum signal resolution can be measured. The ADC converts the applied voltage signal into a binary quantization level that records the voltage level of the signal at that instant in time. These data are then transferred to the digitizer memory.
2. A memory section used to temporarily store the received quantization data. Depending on the functionality of the digitizer, the device can transfer the data to the host PC at the end of the measurement (called the standard mode of operation), or the data can be continuously transferred to the host PC while the measurement continues [we call this first in, first out (FIFO), or streaming mode].
3. A bus section that is the electrical interface to the host computer. Its purpose is to transfer commands to the digitizer for measurement setup and control and to transfer the recorded data to the host PC.
4. A clock section that generates a clock signal that determines the sample rate of the ADC(s). This section provides internal bus synchronization and refreshes the onboard memory devices.
5. A control section to control the previous four sections and transfer the data from onboard memory to the bus.

Many manufacturers produce digitizers that are modular instruments based on one of the standard bus formats (e.g., PCI and PXI).

The signal that would be digitized early would be the preamplifier signal from the HPGe detector, and software programs written in C would be used to provide shaping, filtering, and other needs behind the information barrier.

For example, Zeynalova et al.[3] developed digital signal processing algorithms for nuclear spectroscopy. The experimental setup consisted of an HPGe detector and associated preamplifier. The output of the preamplifier was fed into a digital oscilloscope sampling at a rate of 5×10^9 samples/second. The oscilloscope was controlled by a PC through an Ethernet connection. Software algorithms were written to perform filtering, pile-up rejection, and other pulse-processing techniques.

ORTEC manufacturers the DSPEC and DSPEC Pro, which are advanced digital gamma-ray spectrometers for HPGe systems. These spectrometers are waveform digitizers with other circuits for filtering and shaping. However, these spectrometers have many features that are not needed for the AMS system. We can consider building a simplified version of one of these spectrometers and using it in the AMS, but it may increase costs.

3.2 Discussion

If data reduction and analysis were done in software, the user would have the ability to modify the algorithm during the troubleshooting phase if a different analysis routine were preferred (e.g., if different parameters were preferred). Also, it may be more difficult to spoof the system because the software can be written to look for unusual circumstances, such as anomalously high count rates.

The hardware will be more modular, where the developer does not have to adjust the actual circuits as in a hardware-centric system. The physical components could have better robustness and reliability than custom-made ones because they would have been tested in the marketplace and improved by the manufacturer. Also, the cost could be lower than a custom-made component because the manufacturer could spread the development cost over many customers.

In a software-centric system, the researcher can reprogram the code with new parameters. In a hardware-centric system, if an adjustable parameter runs out of range when the developer is trying to optimize the system during the troubleshooting phase, the developer may be forced to physically de-solder the offending components and alter the circuit.

4 SOFTWARE AUTHENTICATION AND VERIFICATION

Authentication of a software-centric measurement system relies heavily on being able to authenticate the software. Source code must be correct, and the binary representation running on the processor must match that code.

Ideally, teams from the host and monitoring parties would work jointly on writing software for the AMS and would each take a copy home and install the software. Later, a bit–by-bit comparison could be made to verify that they are using the same code/executable.

The preferred computer language would be C because it works at a relatively low level, which makes it an efficient language to use. Many applications are written in C, and it continues to adapt to new uses. C has many strengths: it is flexible and portable, can produce fast compact code, provides the programmer with low-level routines to control hardware (e.g., input and output ports), and provides operating system interrupts.

To create the assembly language version of the program, the developers would compile and debug the program on another computer (e.g., a desktop computer in an office) and install the compiled program on the computer in the AMS.

A program that is simple, straightforward, and easy to understand is easier to authenticate "by hand." The logic can be examined to identify what is logical.

Most commercial, off-the-shelf software packages come with powerful analysis programs that are in use every day by millions of people worldwide. Therefore, the authentication philosophy "should" be readily acceptable. Short, simple, straightforward programs are easier to understand and to authenticate by hand.

5 CONCLUSION

As many examples have shown, software-centric systems with the appropriate hardware can be used for the many functions required for an AMS. Also, if reconfiguring the system is necessary during the troubleshooting phase, software may be easier than hardware to reconfigure. Authentication, although difficult for both hardware and software, can be accomplished in software-centric systems by hand if simple, short, and straightforward programs are used.

Certainly, the requirements for a deployed AMS will depend on the negotiations between the treaty partners.

6 REFERENCES

1. Jonathan Thron, Kate Frame, Peter Karpius, and Norman Johansen, "Next Generation Attribute Measurement System," Los Alamos National Laboratory report LA-UR-08-03802 (2008).

2. J. Bagi et al., Neutron Coincidence Counting with Digital Signal Processing, *Nucl. Instr. and Meth. A* (2009).

3. Zeynalova et al., "Application of Digital Signal Processing in Nuclear Spectroscopy," *Bulletin of the Russian Academy of Sciences, Physics*, 2009, **73**:4, 506–511.