Conf-940307--11

LA-UR- 94-0276

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Submitted to: IAEA Symposium on International Safeguards
Vienna, Austria
March 14-18, 1994
(FULL PAPER)

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IAEA-SM-333/92

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ADVANCES IN AND USES OF GAMMA-RAY FIELD INSTRUMENTATION AT LOS ALAMOS*

1. Introduction

We are developing a set of tools to be used by the Safeguards Assay Group to solve problems found in safeguards and the domestic nuclear industry. The tools are also applicable to problems dealing with the environment, defense, and other areas of national and international interest.

We have used extensively the advances in hardware and software since our last multi-channel analyzer (MCA) development activities over a decade ago. We are also using our experience with and feedback from users of our previous instruments.

In analyzing the instrument needs of our constituents and the characteristics of our previous instruments, which we think have inhibited their broader use, we have concluded that

- uses for an MCA-type instrument are widely varied and fundamentally changing,and that any new instruments should include

- a versatile, widely used hardware interface, which is as independent as possible of hardware standards, and which is

- readily interfaced to the computers or controllers rapidly evolving in the commercial sector.

*Work supported by US Department of Energy, Office of Safeguards and Security.

In addition, software tools must be provided that

- allow Los Alamos, users, and third parties to quickly and conveniently develop software specific to the user or the measurement to control the basic instrument we develop.

This paper deals mainly with a miniature and modular multi-channel analyzer (M^3CA) and its applications. For more specific hardware, software, and functional details, see Ref. 1.

2. The system being developed

Our system, the M^3CA, is composed of a basic MCA, which includes hardware and firmware, and a software library that provides an interface between programs written in high-level languages and the basic MCA (Fig. 1).

The M^3CA is targeted at applications that we feel are not adequately addressed by commercial instruments such as in-field or in-plant measurements where the instrument must be carried by a user who needs his or her hands free. We are not directly targeting network-based systems, although we do have the potential to connect to networks. A unique and significant feature of our system is that our software allows the M^3CA to be easily integrated into an existing or user created measurement system; many commercial systems require the user measurement be built into their specific software and operating system. Our software flexibility also allows a user to easily implement new user software on virtually any computer platform.

From the hardware standpoint, the M^3CA provides all the necessary support for typically used detectors, bias, low-voltage power, and variable time constants. The performance of the analog electronics is comparable with rack-mounted and mains-powered systems (Fig. 2). The present M^3CA is smaller in volume than any other unit (10 x 20 x

9 cm), and we are reducing its volume by approximately 50%. Its form factor allows it to be conveniently carried on a belt or shoulder strap. It is approximately 60% of the weight of commercial units in its larger form. The unit is powered by a removable, internal 12 V, 2.2 Ah NiMH computer battery that can be carried in a shirt pocket. The battery life is approximately 3.5 to 4.5 hours depending on the load presented by the detector.

The M^3CA's hardware includes a high-performance amplifier with two selectable time constants, fine and coarse gain adjustments, pulse pile-up rejection (PUR) and dead-time correction, and active, gated baseline restoration (BLR). The PUR and BLR have automatic thresholds. The ADC is a Wilkensen type with 512 and 4096 channel conversion gains. It has two 4096 channel conversion memory banks that can be partitioned into 256 to 4096 channel groups. A unique feature of the hardware is digital differential nonlinearity smoothing. The power supply board provides low-voltage and bias power for standard detectors. The processor board has three serial ports, 16-bits of binary I/O, nonvolatile EEPROM for parameter storage, and a FLASH ROM disk for program storage. A more complete list of features is given in Ref. 1.

The firmware of the M^3CA controls the hardware in response to commands that come over a serial interface. The command set includes control for *every* hardware function, a read of all status, and control and read back of resident gamma-ray measurement functions. The commands are serial ASCII strings composed of an opcode optionally followed by one or more arguments and terminated by a carriage return. Responses are also ASCII with the one exception of spectral data transfer, which can be either ASCII or binary

The serial interface was chosen because it is widely used and available on virtually all computers and controllers. While the serial interface is slower than a parallel or bus interface, the firmware has been designed to minimize the need for high-data transfer rates by doing binary data transfers, transferring variable numbers of bytes per channel, allowing data transfer while acquiring, and by doing basic calculations in the M^3CA.

In addition to controlling the hardware settings of the M^3CA, the firmware handles communications and internal diagnostics and performs basic gamma-ray measurement macros such as region of interest (ROI) operations and centroid calculations. Therefore, the M^3CA can make calculations locally from spectral data and pass only the results to the controller instead of the total spectrum. For example, with software gain-drift compensation, the M^3CA determines the stabilization ROI, calculates its centroid, and sends the results to the controller. On the basis of the transferred results the controller decides whether to change the analysis ROIs.

The embedded control and measurement macros and the simple command structure significantly broadens the field of programmers who can write control and user programs for the M^3CA. With these tools the programmer needs to learn only how to command and make use of the data from the M^3CA. In the past an understanding of how to implement the functionality of the MCA was required.

The M^3CA firmware performs general purpose gamma-ray measurement type functions in response to commands sent by a controller; it does not perform a specific application measurement. Application programs are contained in the controller connected to the M^3CA. To aid the programmers developing applications programs for the M^3CA we provide a library of C functions to facilitate control of the M^3CA. The current library consists of commonly used functions that provide the capability to set up the M^3CA, start or stop an acquisition, check if an acquisition is complete, and read a spectrum from the M^3CA. In addition it provides an I/O control function that allows the programmer to directly access any of the approximately 100 low-level commands defined at the serial port level. The library handles the communication protocol between the controller and the M^3CA; thus the application programmer never has to worry about the actual format or parsing of command and response strings or about handshaking and timing.

3. The Controller

Because the basic gamma-ray measurement techniques are slowly changing while computer and intelligent controller technology is very rapidly changing, we have purposely chosen not to include a controller in the original M^3CA. Instead the user chooses the appropriate controller for the application, and we provide tools to develop and implement the controller software. While the first non-LANL application was implemented on a non-DOS intelligent controller, we expect most controllers to be DOS—or at least computer—based. An array of DOS computers ranging from the low-end HP-100 palm-top computer (Fig. 1) to the very sophisticated DX2-66 or Pentium-based computers can be used; however, one is *not* constrained to DOS or to Intel processors. We do envision the development of a DOS-based front panel, which could be added as in integral part of the physical M^3CA. This front panel would enjoy the use of DOS compatible languages as well as a Personal Computer Memory Card Interface Association (PCMCIA) interface, which allows the use of commercially available memory cards, modems, and even Global Positioning Satellite peripherals.

4. Applications

To check out the hardware during the development, an MCA emulation program was developed using the same software tools provided to users. This program allows for setup of the M^3CA, plots the spectra, calibrates, and provides ROI support. It is not intended to compete with sophisticated programs produced by commercial companies, however, it is functional and it does demonstrate the use of the software tools.

The first non-LANL application, a hold-up measurement system, is described in Refs. 2 and 3. Fundamentally the use of a more sophisticated M^3CA was added to an existing measurement system which included

- computer-based setup of the M^3CA and calibration of the associated detector,

- existing procedures and an intelligent controller for making gamma-ray measurements at thousands of sites in the plant,

- and a data base for analyzing and managing data and generating reports.

The software packaged for this application is entitled HMSII (Ref. 3). It is written in dBASE IV®* and runs on standard PCs and laptops, and a compiled version of this software has been downloaded and tested on palm-sized PCs.

The design of the hold-up measurement plan required personnel with NDA training, extensive experience in holdup measurements, and a knowledge of facility operations. These personnel specify the optimum settings and operating parameters, set up ROIs, and specify measurement procedures at various points in the plant. This information is entered into the HMSII program and data base.

The menu driven program allows one to download measurement information and parameters into the M^3CA and its intelligent controller. Another menu item calls up the MCA emulation program to acquire a spectrum and check the ROI settings. Detector calibration is also a program option. After the calibration is complete, a user takes the M^3CA and controller into the plant where measurement points are identified by bar codes.

Reading the bar code initiates the measurement sequence of positioning the detector, acquiring data, and storing results in the controller. This goes on for approximately 1000 points per shift. At the end of the shift, the controller is returned to the computer where the data are transferred from the controller into the computer data base. Analysis is done, and quality control identifies points still to be measured. A report can also be generated.

During analysis, data from each measurement point are linked with physical and mechanical information associated with the measurement location and with the appropriate

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setup and calibration data to allow an individual holdup assay result to be calculated. Further analysis can combine contiguous quantitative results to give the holdup quantity for each piece of equipment, process line, or area.

Batelle Pacific Northwest Laboratories plans to use an M^3CA in an environmental monitoring project. They will use germanium detectors and a program they developed specifically for this application. The size, weight, form factor, and "programmability" of the unit were considerations in their decision. We will also be using the M^3CA and the software library in joint projects with Lawrence Livermore National Laboratory.

5. Applicability to Safeguards

While the actual measurements and analysis of the holdup application described above are not directly useful to international safeguards, there are many requirements similar to those of the IAEA inspector.

- Measurements are carried out by people who for safety and other reasons should have their hands free.

- There is pressure to make reliable and accurate measurements in very short times under difficult conditions.

- Much information is combined into the final analysis, which is made independently from the measurement instrument and controller.

- At the end of the measurement a result is desired quickly and with minimal interaction by the user.

For IAEA use the inspector could carry the smaller version of the M^3CA in a briefcase along with a lap-top computer loaded with data from IAEA Inspector Field Support System and a palm-top to serve as the M^3CA controller and to store data. The inspector would connect the M^3CA to the lap-top to download setup parameters in the hotel room before leaving for the facility, or at the facility. The small palm-top computer with a facility- or measurement-specific applications program would also be connected to the lap-top to load information that allows measurement results to be calculated at the measurement point, immediately compared to declared value and repeated if anomalous results were obtained. The lap-top computer would not be carried into the measurement area. The palm-top computer attached to the wrist would act as the control panel, user interface, and data recorder for the M^3CA, which is carried on the inspector's belt or a shoulder strap. Holsters for the detector and palm-top keep the inspector's hands free when he is walking through the plant, inspecting items or manually making notes. After the inspector's lunch break, he would exchange the battery in the M^3CA and proceed with the afternoon measurements. At the end of the day the data could be transferred using a serial link between the palm-top and laptop or via a PCMCIA memory card.

Even though the M^3CA is small, it has the quality to make measurements that now require larger, non-portable, mains-powered, and less reliable equipment than the presently used portable MCA (PMCA). The system could be used to acquire plutonium-isotopic data for analysis. The advantage to the IAEA is that one instrument could make all measurements, where before the PMCA could not be used for plutonium measurements. This minimizes inspector and technician training, inventory, and maintenance requirements. The software tools allow the IAEA, Los Alamos, or others to efficiently develop user programs using the M^3CA. Libraries are inherently reusable, making the software cheaper and more reliable.

6. Related developments

For absolute minimum power consumption, we are considering a configuration of the M^{3}CA that would replace the individual analog-to-digital converter and amplifier boards with a single lower-performance board that combines the two functions. Which board(s) is used would be transparent to the user program.

To complement the M^{3}CA we have developed a portable neutron coincidence counter (NCC) electronics package composed of an NCC board with its own processor, and the same housing, battery, power and bias supplies, and communication and command structure that was used for the M^{3}CA. It can also be made to operate in a mode compatible with the JSR-11 or JSR-12. The NCC can be expanded to have multiplicity capability and multiple singles counters. The built-in battery makes it a good candidate to be used in remote and unattended applications. The NCC board can be used alone, in multiples, with the M^{3}CA, or with other boards described below.

We have also designed boards with the function of the gamma-ray and neutron detector boards used with the gamma-ray and neutron detector electronics (GRAND) package. We have enhanced the design of the ion-chamber board for radiation-based monitoring based on operational experience. These boards can be combined with other personality boards. Self-configuration capabilities are included in the basic design of our system.

Software libraries are provided for the various boards and instruments. These libraries can used in control and user programs written in a high-level language such as C, and they can be converted for use with commercial graphical user interface programs such as LabVIEW. They also provide a basis for adapting these instruments to a software standard if one is developed and adopted by the IAEA. Such a standard would allow for efficient and straightforward integration of the variety of instruments used by the IAEA for all types of applications.

Figure Captions

Fig. 1. The M^3CA (right) and palm-top computer.

Fig. 2. The top trace is a high-count-rate spectrum acquired with nuclear instrumentation modules, a Canberra 2020 amplifier, and an 8075 analog to digital converter with pile-up rejection optimally adjusted. Input count rate is 60 k/s. The lower trace is a low-power amplifier in a portable MCA. The portable, low-power unit actually has high performance with regard to the difficult task of pile-up rejection. The resolutions obtained were comparable.