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A UNIQUE COMPUTER SYSTEM FOR SAFEGUARDS USE

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Abstract

Microprocessors have been used to implement specialized scientific data processing systems since 1976. One such system, the LeCroy 3500, is presently being used by the Detection and Verification Group of the Energy Division at Los Alamos National Laboratory for a large variety of tasks involving measurement of various nuclear parameters associated with radioactive materials. The system is unique because it can do not only sophisticated pulse height and multi-scale analyses but also other analyses that are limited only by the availability of CAMAC modules that would acquire data from exotic experiments. The system is also field portable which extends the range of experiments that it can control. Four applications of this system are described in this paper: (1) plutonium storage vault monitoring, (2) coded aperture image reconstruction, (3) spatial distribution of gamma radiation, and (4) nuclear waste management.

1. INTRODUCTION

Microprocessors have been used to implement specialized scientific and business data processing systems since 1976. One such system, the LeCroy 3500, is presently being used by the Detection and Verification Group of the Energy Division at Los Alamos National Laboratory for a large variety of tasks involving measurement of various nuclear parameters associated with radioactive materials. The system is used both in the laboratory and in the field to record gamma and neutron radiation from objects under investigation. The LeCroy 3500 is also used as a general purpose computing system.

1.1 LECROY 3500

The LeCroy 3500 combines the standard features that one expects to find on a microcomputer with some unique features that are not found on other systems in similar price ranges. A picture of a LeCroy 3500 system is shown in Fig. 1. The system is based on the Intel 8085 microprocessor chip set. A floppy disk subsystem supports a file-oriented operating system that allows the use of both Assembly language and FORTRAN programs. A built-in typewriter keyboard and a CRT display perform the function of a terminal and hard copy output can be made on the line printer. A block diagram of the LeCroy 3500 computer system is shown in Fig. 2. The features listed above are usually found on many of the microcomputer systems that are present in today's marketplace. The LeCroy 3500 possesses a number of features that make it uniquely suited for data acquisition from and control of scientific experiments. An eight-slot CAMAC minicrate allows electrical and software interfacing to an extremely broad range of experiments. The data collected by CAMAC modules in the minicrate can be stored in the histogram memory at rates up to 1 MHz. Data collected from the experiment can be displayed on the CRT in graphical form using the display processor capabilities of the CRT. The 64k memory address space has been broken into two 32k pieces. The upper 32k is populated by read/write memory while the bottom 32k is dynamically populated with one of up to eight 32k physical memories under control of the memory management unit. These physical memories can be read/write memories or read only memories (ROM). An arithmetic processing unit based on the Advanced Micro Devices 9511 chip set allows execution of integer and floating point arithmetic in this computer system.

1.2 CAMAC MINICRATE

The minicrate holds 8 single width CAMAC modules. Moreover, the CAMAC controller will support the addition of full size (25 slot) CAMAC crates to the system. The CAMAC interface can work in one of two modes: direct memory access (DMA) and programmed input or output. The DMA mode allows transfer of data from specially designed LeCroy CAMAC modules to the histogram memory at rates up to 1.0 MHz. Included in the list of special modules are the LeCroy 3511 and 3512 which are used for pulse height analysis, the LeCroy 3521 which is used for multichannel scaling, and the LeCroy 3541 timer module. The central processing unit of the 3500 can be executing a program simultaneously with DMA activity in the minicrate. Any standard CAMAC module including the DMA modules discussed above can be accessed by the central processing unit using the Intel 8085 input and output instructions or the FORTRAN-callable subroutines supplied by LeCroy. This allows all of the CAMAC modules on the market today to be used to interface this computer system to almost any scientific experiment.

1.3 HISTOGRAM HISTORY

Because the 64k by 8 bit address space of the 8085 processor is not adequate for applications that produce large amounts of data, a separate 64k by 24 bit memory is available for data storage. This memory is directly accessible by the special DMA CAMAC modules described above and as an I/O device on the Multibus by the 8085 central processing unit. Normally data generated by the pulse height analysis and multichannel scaling modules are accumulated in the histogram memory.

1.4 DISPLAY PROCESSOR

The keyboard and CRT display perform the function of the system console for input and output of ASCII character information. A display processor using an Intel 8085 microprocessor controls the display function of the CRT. In addition to display of alphanumeric data, a FORTRAN-callable pen-plotter graphics library is available. The raster scan display is driven by a display processing language and is dot-oriented with dimensions of 512 dots horizontal by 256 dots vertical. Suitable manipulation of the dot field allows for crude gray scale image plotting.

1.5 MEMORY MANAGEMENT

The Intel 8085 microprocessor supports a memory space of 64k. A memory management scheme maps the upper 32k of this logical memory to 32k of read/write memory while the lower 32k is mapped to one of 8 physical memories of 32k locations each. One of these memories consists of read/write memory and the remainder consists of read only memories (ROM). This allows for reliable operation of programs in the field without disk support. Presently, two ROM-based programs are available from LeCroy: (1) Multichannel Analysis (MCA) program and (2) Autoanalysis program. The MCA program performs sophisticated pulse-height analyses and multichannel scaler analyses. The data collected is then displayed in a variety of calibrated and uncalibrated formats on the CRT. The Autoanalysis program is used to operate the MCA program automatically. This is useful when a large number of repetitive MCA program operations are required.

2. SAFEGUARDS APPLICATIONS

The LeCroy 3500 has been used in a number of nuclear parameter measurement applications in the safeguards area. Four such applications will be discussed in this paper. These are: (1) monitoring of a plutonium storage vault to prevent diversion of small amounts of material; (2) analysis of coded aperture images from gamma scintillation cameras; (3) measuring spatial distribution of gamma radiation from a source under test; and (4) assay of nuclear waste material.

2.1 PLUTONIUM STORAGE VAULT MONITORING

Various Department of Energy Facilities possess large inventories of plutonium. While security at these installations is strict, research in the prevention of diversion of small amounts of this nuclear material is continuous. Because plutonium is a spontaneous neutron emitter, the neutron count rate field in a typical storage vault can be measured at 25 locations with the idea of detecting movement of material by measuring distortions in the measured neutron field. An array of 25 ^{3}He neutron detectors were distributed in a 5 by 5 grid in the ceiling plane of a typical storage vault. A photograph of a test configuration of this experiment is shown in Fig. 3. The data from these 25 detectors were then routed to 25 each 24-bit scalers that were housed in 5 CAMAC modules in the minicrate. The data from these scalers along with an accurate counting time were then acquired by the central processing unit of the 3500 which converted it to count rate data for the 25 vault locations. The count rate data were analyzed using Chi-Square statistical techniques and probabilistic estimates of whether the field had significantly changed since some previous measurements were made.

After 8 months of monitoring the test vault, it was determined that small amounts of material movement could be detected given stable electronics and power supplies. Briefly, it is possible to detect movement of 1 kg of 11% ^{240}Pu out of a total inventory containing in excess of 2500 kg. Additionally, it was possible to observe the effect of an open vault door and/or personnel in the vault even when no material was being moved.

2.2 CODED APERTURE IMAGE ANALYSIS

It is desirable to image radioactive sources, such as found in nuclear waste, that may be present in a container without opening the container. If the gamma rays emitted by the source in question are numerous enough, a pin-hole aperture in front of a gamma-imaging device is sufficient to form a reasonable image. A source producing small amounts of gamma radiation will at least require a very long time to produce a pinhole image; however, a long counting time may allow noise accumulation such that a usable image is never acquired. A coded aperture consists of many pinholes through which a source with small amounts of radiation can cast numerous shifted images on the imaging device. The total image must be decoded using correlation techniques before it becomes useful. If the coded aperture is carefully selected, Hadamard transform optics theory can be used to decode the image.

At present, mathematical routines to decode and display coded aperture images with 9207 pixels (99 by 93) have been written and tested on the LeCroy 3500. Fig. 4 shows the coded image of a simulated point source. The coded image of a point source is also the pattern of the coded aperture used to image the source. The decoded image is shown in Fig. 5. More complex sources can be imaged. The simulated coded image of a source distributed between two concentric circles is shown in Fig. 6. The decoded image is shown in Fig. 7. These figures were made using seven-level gray scale routines and the display processor of the 3500. The decoding requires approximately 45 seconds using fast inverse Hadamard transform techniques and the arithmetic processing unit of the 3500 system.

2.3 SPATIAL DISTRIBUTION OF GAMMA RADIATION

It is desirable to determine the spatial distribution of gamma radiation being emitted by a source in a sealed container without opening the container. Gamma-ray energies are characteristic of the emitting materials, so the spatial distribution of the distinctive gamma-rays maps the distribution of different materials. A two-dimensional mechanical scanner driven by stepper motors was built. A collimated germanium detector is mounted in the scanning device. This detector then measures the gamma radiation for each spatial location in the scan. The MCA program is used to set up the data acquisition and plotting parameters. Then a program written in FORTRAN controls the stepper motor and acquires gamma photopeak data for each energy range specified and at each spatial location specified. The areas of as many as 16 photo peaks for each of up to 100 spatial locations can be determined.

2.4 ASSAY OF NUCLEAR WASTE

Nuclear waste from early experiments occasionally has been stored in drums and crates awaiting retrieval at a later time. In some cases, the records describing the contents of individual drums and crates are inadequate or have been lost. It is desirable to identify the contents of selected containers without opening the container. In one such experiment, initial measurement techniques included: (1) spectral measurement of gamma emissions, (2) thermal neutron interrogation, and (3) radiography. The results of these measurements were inconsistent with each other. The directly-produced low-energy gamma rays and the other gamma rays with greater penetrating power suggested potentially large quantities of material and neutron measurements indicated small quantities of nuclear material, while the radiographs showed large chunks.

The containers of nuclear waste were then interrogated with highly penetrating 8 MeV gamma rays. This caused photofissioning in the nuclear material, resulting in neutrons whose quantity die away at characteristic time rates. This die-away time was measured by multichannel scaling. Comparisons were then made with die-away times for known quantities and types of materials. At this point, the quantity and type of material present could be identified and the results explained the earlier inconsistency.

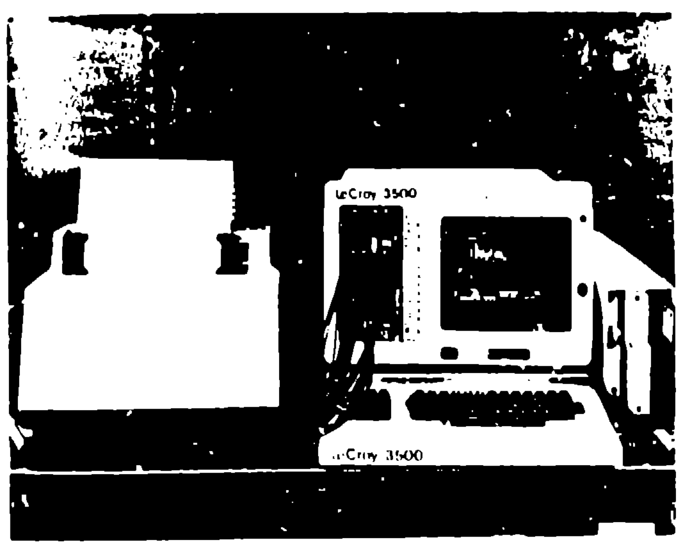

Fig. 1. LECROY 3500 COMPUTER SYSTEM

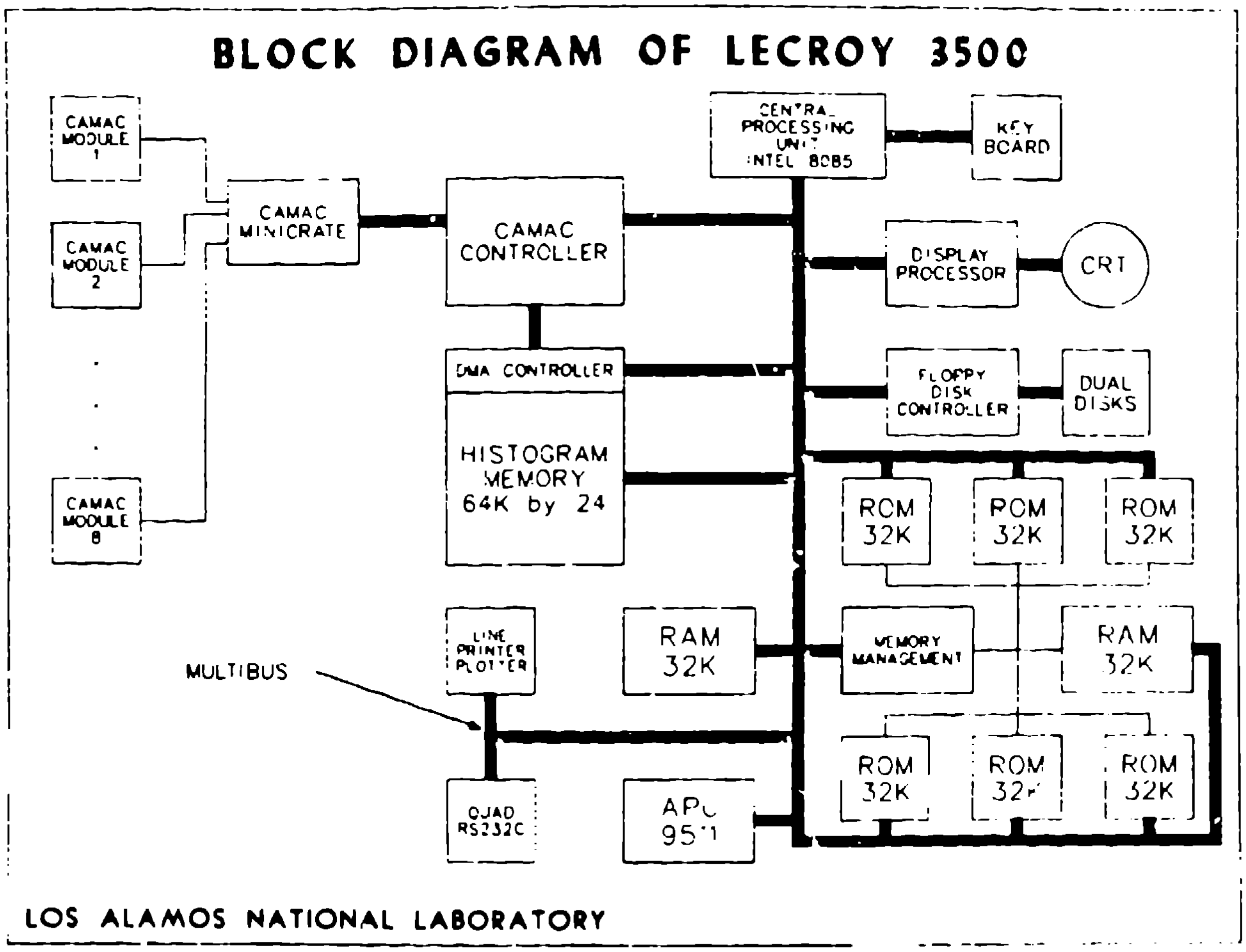

Fig. 2.

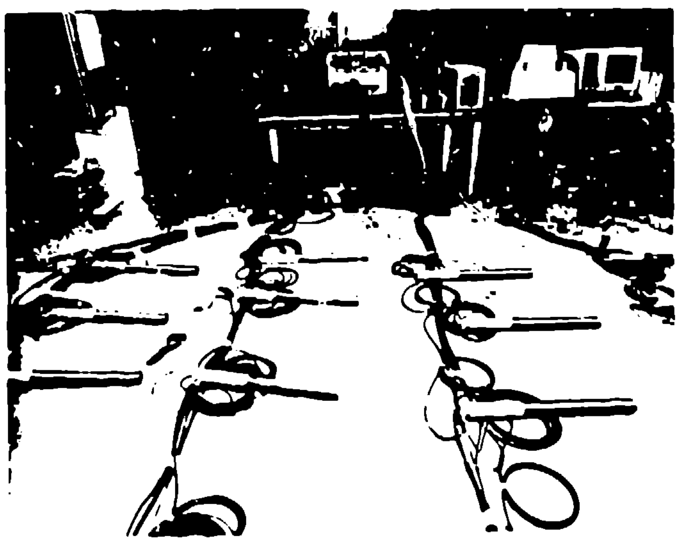

Fig. 3. TEST CONFIGURATION FOR PLUTONIUM STORAGE VAULT MONITORING

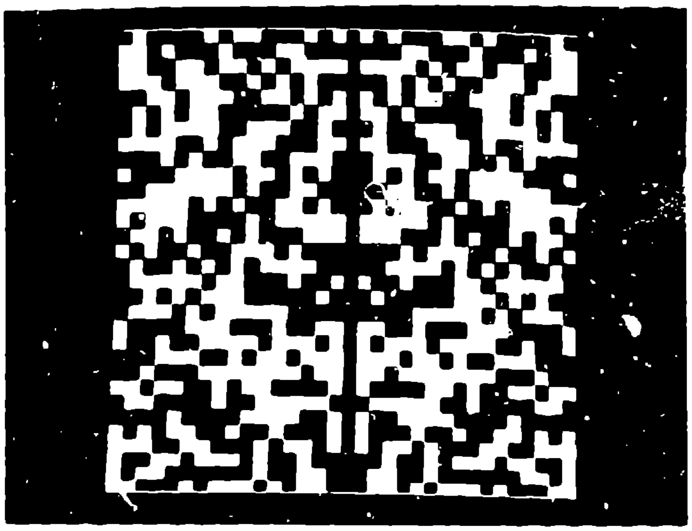

Fig. 4. CODED IMAGE OF SIMULATED POINT SOURCE

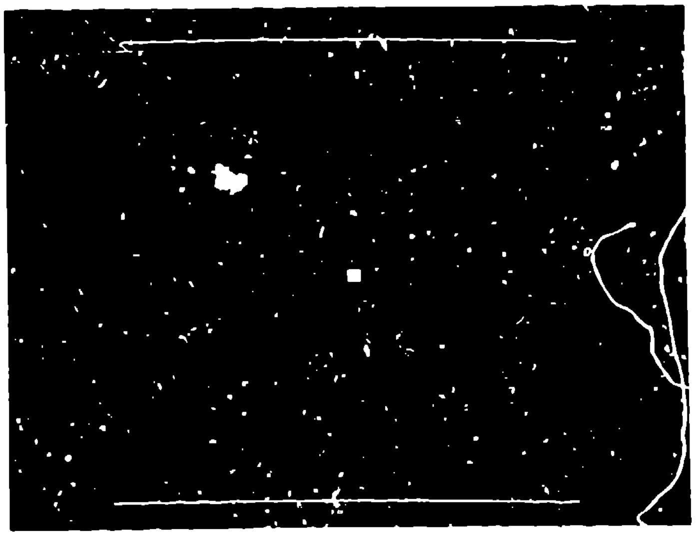

Fig. 5. DECODED IMAGE OF SIMULATED POINT SOURCE

Fig. 6. CODED IMAGE OF A SIMULATED DISTRIBUTED SOURCE

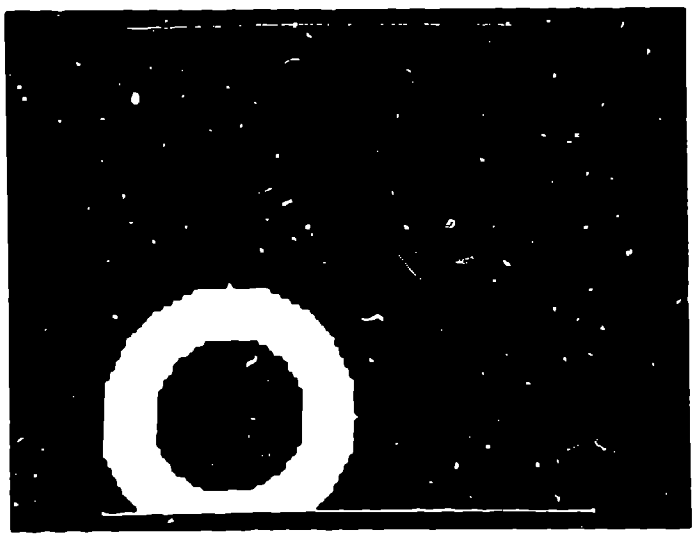

Fig. 7. DECODED IMAGE OF A SIMULATED DISTRIBUTED SOURCE

3. BIOGRAPHIES

Thomas H. Kuckertz was born on May 27, 1945 in Chicago Illinois. He is the holder of a B.S.E.E.(1968) degree from the University of Illinois, Urbana, Illinois and M.S.E.E. (1969) and Ph.D. (1974) degrees from the University of Idaho, Moscow, Idaho. Dr. Kuckertz presently holds the position of Staff Member at the University of California Los Alamos National Laboratory where he is currently engaged in the design and development of custom mini/micro-computer systems. Prior positions held include Communications Officer for the United States Army Signal Corps and Electrical Engineer for Illinois Bell Telephone Company. He is a registered Professional Engineer in New Mexico and Illinois, and is a member of the following technical societies: Institute of Electrical and Electronics Engineers and Association for Computing Machinery. Dr. Kuckertz also teaches courses in design of digital systems at the University of New Mexico Graduate Center, Los Alamos, New Mexico.

John C. Pratt earned his B.S. in physics at North Carolina State University and his Ph.D. degree from Stanford University. His thesis was written in the field of High Energy Physics from research at Stanford Linear Accelerator Center. He participated in experiments at the Los Alamos Meson Physics Facility to measure branching ratios for rare pion decays, crosssections for n-p scattering, and +H-ion photo-detachment crossections. He joined the Detection and Verification group at Los Alamos National Laboratory in 1977. Since then he has worked on projects for Fast Critical Assembly and Uranium Separation Facility safeguards, Portal Monitor improvements, and Waste Management screening.