Acquisition of Gamma Camera and Physiological Data by Computer

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We have designed, implemented, and tested a new Research Data Acquisition System (RDAS) that permits a general purpose digital computer to acquire signals from both gamma camera sources and physiological signal sources concurrently. This system overcomes the limited multi-source, high speed data acquisition capabilities found in most clinically oriented nuclear medicine computers. The RDAS can simultaneously input signals from up to four gamma camera sources with a throughput of 200 kHz per source and from up to eight physiological signal sources with an aggregate throughput of 50 kHz. Rigorous testing has found the RDAS to exhibit acceptable linearity and timing characteristics. In addition, flood images obtained by this system were compared with flood images acquired by a commercial nuclear medicine computer system. National Electrical Manufacturers Association performance standards of the flood images were found to be comparable.

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The use of digital computers in nuclear medicine departments to acquire, process, store, and display scintillation camera images has become commonplace. The clinical computer systems generally available today support data input from one or two gamma cameras with data rates limited to ~50 kHz. These computer systems are not designed to input data from sources other than gamma cameras during the course of a study. However, in many research applications it is necessary to input physiological signals from various transducers in conjunction with the gamma camera data input. The advantages of acquiring a temporal sequence consisting of gamma event data and physiological data is significant. An example of this temporal merging of physiological and gamma event data is the simultaneous collection of electrocardiograms and nuclear cardiology data in order to provide *a posteriori* gating and formatting information for the gamma event data (*1*). Another example of this temporal data merging is the simultaneous collection of nuclear event data and respiratory function data from an impedance plethysmograph or a pneumotachometer in order to study the respiratory motion of the lungs or other organs (*2,3*).

Other research protocols require moderately high input data rates in excess of 50 kHz for short periods of time. The first-transit, time-activity method of computing ejection fraction is one such example of the need to collect nuclear event data at high data rates for limited periods of time (*4*). Data are collected for a period of 60 sec for this technique. In an attempt to overcome these limitations of commercial nuclear medicine computer systems, we have designed and implemented a Research Data Acquisition System (RDAS) which features acquisition of up to eight physiological signals concurrently with the acquisition of gamma camera data from up to four sources. The throughput of the system is an aggregate 50 kHz for the physiological signals and 200 kHz for each gamma camera input. Due to the limited data buffering capabilities included in the RDAS, either the target computer system must have an I/O data rate capacity greater than that of the RDAS, or the RDAS—computer interface must provide additional data buffering to permit the transfer of short duration, high speed data bursts between the RDAS and the host computer. For the case of operating the RDAS with one gamma camera input operating at 200,000 7-bit samples per second and with two physiological signal channels operating at 25,000 12-bit samples per second each, the host computer I/O throughput capacity must exceed 500 kbytes/sec.

Various researchers have overcome the problem of the lack of physiological signal input capabilities by clinical nuclear medicine computers by implementing preprocessing hardware that enables the physiological

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signals to emulate a second gamma camera channel (*1*). However, this scheme limits the input capabilities of the acquisition system to one gamma camera channel and one physiological channel. We approached the above two problems simultaneously. We, like many other research groups, tend to acquire our research studies on a clinical computer system but then transfer the image data through magnetic tape to a larger, general purpose computer system for subsequent processing and display. Our research processor is a 32-bit Data General* MV/6000 computer. In order to overcome the data acquisition limitations of the clinical computer systems, we have implemented the RDAS to allow our research computer to directly acquire scintigraphic images and physiological data.

The design goals were as follows: (a) to design and implement a stand alone data acquisition system capable of interfacing to a large range of computer systems; (b) to provide multiple data input streams from physiological as well as gamma camera sources; (c) to merge the multiple data input streams into a single output stream in which data are positioned temporally; (d) to include flexible data formatting schemes that are user selected; and (e) to provide software controlled, hardware implemented gain and offset adjustments for all gamma camera signal inputs.

TECHNICAL DESCRIPTION

The RDAS is housed in its own 19″ wide × 5.25″ high × 12″ deep circuit card rack. It includes up to four gamma camera A/D subsystems and a physiological A/D subsystem which will accept up to eight bipolar analog input signals over a range of ±10V. The gamma camera A/D subsystems each have a throughput rate of 200,000 samples per second and support dual energy input. Resolution for both the physiological A/D subsystem and the gamma camera A/D subsystems are user selected for either 7- or 12-bits. In addition, the format of the data obtained by the A/D subsystems and transferred to the host computer is user selected. The basic data word supported is 16-bits. This word length is compatible with most micro- and minicomputers but can be modified in the computer interface for host machines that use different word lengths.

Two data formats are provided for the physiological A/D subsystem as shown in Fig. 1. Format 0 provides 12-bits of A/D resolution with a single 12-bit data word and a 4-bit identifier packed into each 16-bit computer word. This format consists of one bit identifying the source of the data as the physiological A/D subsystem (bit 0, MSB), three bits identifying the A/D channel number (bits 1–3), and 12 bits of converted data (bits 4–15, where bit 15 is the LSB). Format 1 is used when a reduced A/D resolution of 7-bits is desired with data packing of two converted data points per 16-bit computer word. This format consists of one bit identifying the source of the data as the physiological A/D subsystem (bit 0), one bit for addressing the A/D channel pair converted (bit 1), the most significant 7-bits of the first channel of the channel pair converted (bits 2–8), and the most significant 7-bits of the second channel of the channel pair converted (bits 9–15). Note that bit 1 of this format addresses four channel pairs with only a single bit. Since this single bit cannot uniquely identify all four channel pairs, the programmer must have some *a priori* knowledge of the number of channels and the addresses of the channels that are being converted during a

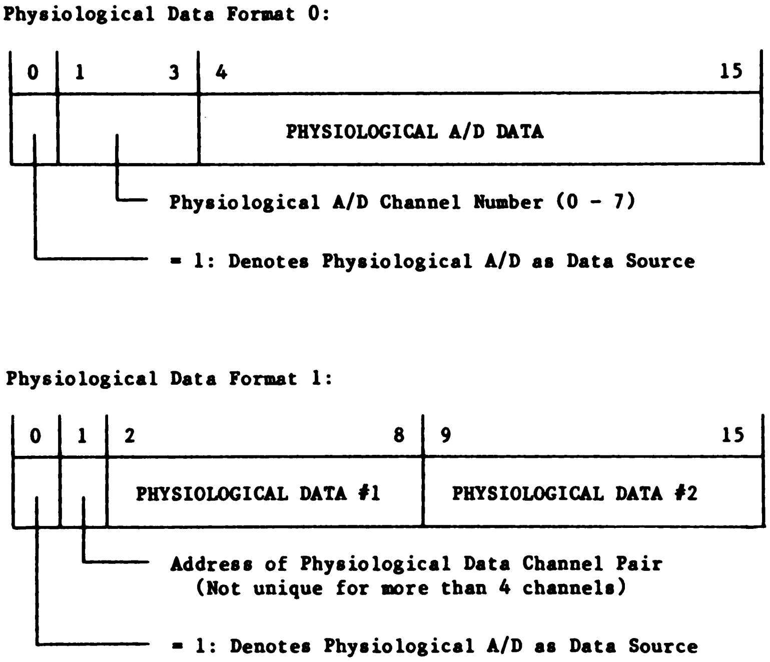

FIGURE 1
Physiological A/D data format

(Physiological data consists of the 7-most significant bits of the A/D output. Bits 2 - 8 represent data from first channel in pair and bits 9 - 15 represent data from second channel in pair.)

particular study. Note also that the same data format is selected for all physiological channels enabled.

Figure 2 shows the three data formats which are provided by the gamma camera A/D subsystems. Format 0 provides 12-bits of A/D resolution and stores the converted data from the X- and Y-gamma camera channels in separate, contiguous data words. During data transfer to the host computer, these two data words are sent as a pair. This format of the two similar words consists of one bit identifying the source of the data as the gamma camera A/D subsystem (bit 0), two bits containing the least significant two bits of the gamma camera subsystem address (bits 1–2), one bit for identifying either the X- or Y-gamma camera channel (bit 3), and 12-bits of converted data (bits 4–15). Format 1 provides a reduced A/D resolution of 7-bits with the data from both the X- and Y-channels packed into a single 16-bit computer word. This format consists of two bits of gamma camera A/D subsystem address (bits 0–1), 7-bits of X-channel data (bits 2–8), and 7-bits of Y-channel data (bits 9–15). Format 2 differs from Format 1 in that it permits dual energy data acquisition. With Format 2, two Z-pulse inputs are enabled for each gamma camera and the Z-pulse address of gamma input event is sent to the host computer. This format consists of one bit with the LSB of the gamma camera A/D subsystem address (bit 0), one bit denoting which Z-pulse was received by the A/D subsystem (bit 1), 7-bits of X-channel data (bits 2–8), and 7-bits of Y-channel data (bits 9–15). Note that in Formats 1 and 2, bits 0–3 do not provide complete addressing information of the source of the converted data. Therefore, these formats must be used in conjunction with *a priori* knowledge of the channels employed for a particular study. Note also that the same data format is selected for all gamma camera channels enabled.

All of the parameters needed to control the RDAS are provided through software and are transferred to the RDAS from the host machine through the communications interface. These control parameters are listed in Table 1. The parameters can be classified as follows: subsystem enable, format select, physiological A/D subsystem control, and gamma camera A/D subsystem control.

The RDAS consists of four subsystems as depicted in Fig. 3. The first is the gamma camera analog-to-digital conversion subsystem. This module is used to acquire positional and energy data from a standard gamma camera. There may be up to four of these subsystems within the RDAS. The second subsystem is the physiological signal analog-to-digital subsystem. This module is used to synchronously acquire data generated from up to eight devices that generate analog electrical outputs. The third subsystem is the control and communications module whose task is to assure error free com-

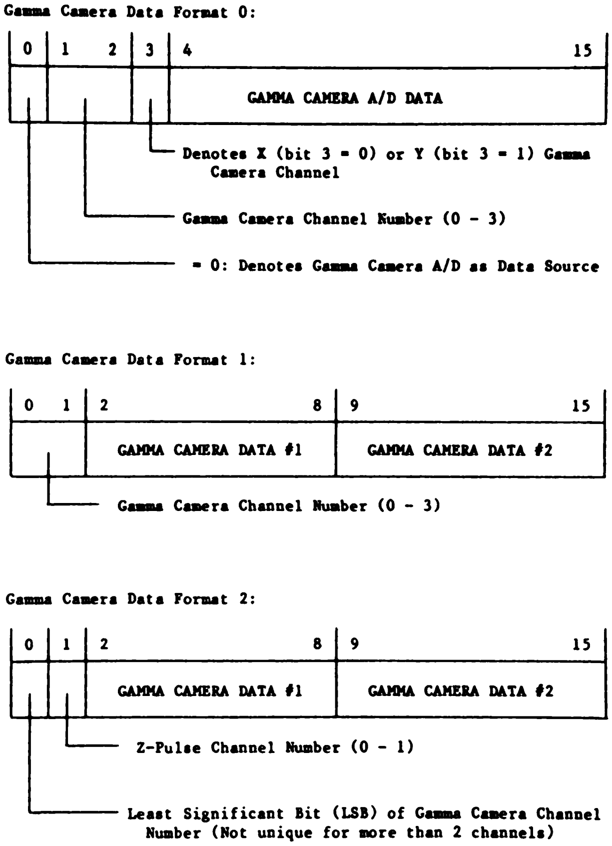

FIGURE 2
Gamma camera A/D data format

TABLE 1
Research Data Acquisition System Control Parameters

Bits	Function
Physiological A/D Control Word #1:	
0–2	Physiological A/D Start Channel (0–7)
3–5	Physiological A/D End Channel (0–7)
6–7	Real Time Clock Frequency (00 = >100 Hz, 01 = >1 kHz, 10 = >10 kHz, 11 = >100 kHz)
8–15	01000000
Physiological A/D Control Word #2:	
0–3	Real Time Clock Frequency Divider (2–10)
4	Internal/External Real Time Clock (0/1)
5–7	Number of channels or channel pairs (depending on data format) to transfer following data conversion
8–13	010000
14	Physiological Data Transfer Format (0–1)
15	1
Gamma Camera A/D Control Word:	
0–7	Offset or gain adjust parameter (0–255)
8–9	00
10	Enable Gamma Camera Channel #1
11	Enable Gamma Camera Channel #2
12	Enable Gamma Camera Channel #3
13	Enable Gamma Camera Channel #4
14	Select Offset/Gain Adjustment (0/1)
15	Select X/Y Channel (0/1)
Master Control Word:	
0–1	Gamma Camera Data Format (0–2)
2	Enable Physiological A/D Subsystem
3	Enable Gamma Camera Channel #1
4	Enable Gamma Camera Channel #2
5	Enable Gamma Camera Channel #3
6	Enable Gamma Camera Channel #4
7	Select Polarity of External Real Time Clock ± (0/1)
8–15	10000000

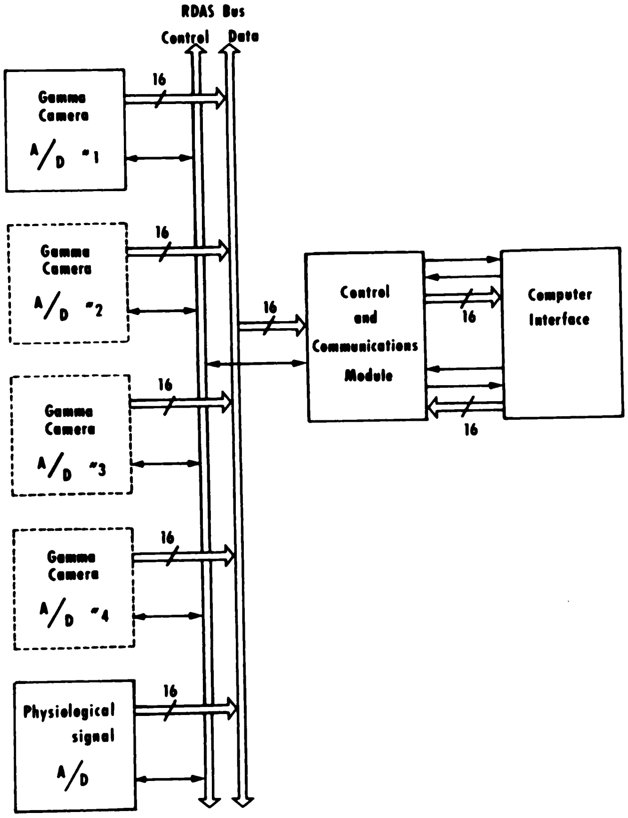

FIGURE 3
Research Data Acquisition System block diagram

munications between the computer interface and the gamma camera A/Ds and the physiological signal A/D in a contention free manner. The fourth subsystem is the computer interface. The computer interface is the only subsystem of the RDAS whose design and function is dependent on the computer employed. It communicates with the control and communications subsystem through a standard "handshaking" interface.

The gamma camera analog-to-digital subsystem consists of two Z-pulse signal conditioning circuits, two fast sample and hold modules, two high speed analog-to-digital converters, two multiplying digital-to-analog converters, two digital-to-analog converters, a data formatting and controlling section, a first-in first-out (FIFO) buffer, and an interface to the internal RDAS bus. This subsystem is represented schematically in Fig. 4. An asynchronous event occurring at either of the two gamma camera Z-pulse inputs triggers this subsystem. The Z-pulses are conditioned by the Z-pulse conditioning circuits to permit transitions or levels of either polarity and any voltage to be accepted as valid Z-pulses. These conditioned Z-pulses are accepted by the conditioning circuit only if the previous A/D conversion has been completed. If the previous A/D conversion has not been completed, the current Z-pulse is ignored. An accepted Z-pulse triggers the sample and hold circuits to hold the X- and Y-input values which are then routed to the multiplying D/A converter. The multiplying D/A converter acts as a variable gain element and amplifies the incoming X- or Y-signal by a preselected constant. The output of the multiplying D/A is routed to a summing circuit which adds the analog voltage output of the multiplying D/A converter to a preselected constant offset voltage generated by the D/A converter. This scheme permits software control of both the gain and voltage offset applied to the incoming X- and Y-signals. Thus, gamma cameras of arbitrary output characteristics may be used with the RDAS, and spatial calibrations are software controlled but implemented in the hardware (5). The output of the summing circuit is routed to a high speed A/D converter where the input X- or Y-signal is converted in 3 μsec to a digital word of 12-bits. Depending upon the preselected data format, either the entire 12-bit data word or the most significant 7-bits of the data word are transmitted to subsequent circuits of this module. These digital data are combined with the output of the other on-board A/D converter (one for the X-channel and one for the Y-channel) according to the preselected data format and is routed along with status bits to the FIFO buffer where it awaits access to the internal RDAS bus. For data format modes that require

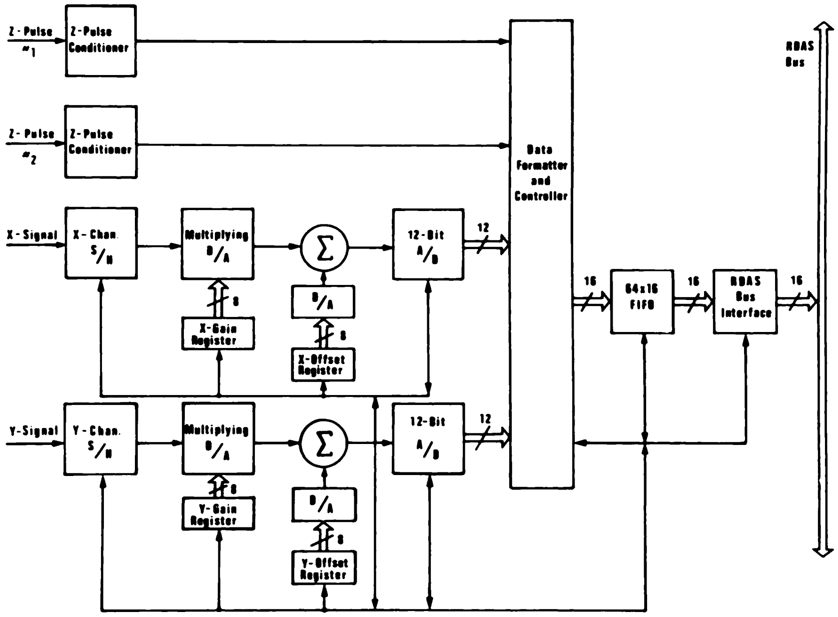

FIGURE 4
Gamma camera A/D subsystem block diagram

two 16-bit output words per conversion, the RDAS bus access request is delayed until both 16-bit words are generated. The total acquisition time for a single gamma camera event is 5 μsec. This is the minimum time permitted between events for Z-pulse acceptance. Therefore, the maximum data rate permitted by the gamma camera A/D subsystem is 200 kHz.

The physiological signal analog-to-digital converter subsection contains a commercially available data acquisition system which includes, an eight input multiplexor, a sample and hold circuit, and a 12-bit A/D converter. In addition to the data acquisition system, the physiological signal A/D module consists of a software controlled internal real-time clock, a data formatting section, a first-in first-out (FIFO) buffer, and an interface to the internal RDAS bus as shown in Fig. 5. With each "tick" of either the internal real time clock or an external clock if so selected, the data acquisition module sequentially inputs an analog voltage from each selected input channel and performs an A/D conversion on each. The A/D conversion may have a preselected resolution of either 7- or 12-bits. The output from the data acquisition module is formatted and routed along with status bits to the FIFO buffer. After all of the channels requested have been acquired and converted, the physiological signal A/D system requests and is subsequently granted access to the internal RDAS bus to transmit its acquired data to the host computer. The conversion time per channel of physiological data is 20 μsec. Therefore, an aggregate throughput rate of 50,000 samples per second is realizable by this subsection.

The control and communications subsystem is the central element of the RDAS. It is used to arbitrate requests from the gamma camera A/D and physiological A/D subsystem for access to the RDAS internal bus. It is also used to insure that the bus is "released" by the module that is presently accessing it to make certain that no subsystem will become locked out of the bus. Finally, the control and communications subsystem is used to pass data from the RDAS to the host computer interface and from the host computer interface to the RDAS.

Data that are transferred to the internal RDAS bus are transmitted by the control and communications subsystem through a standard protocol to a parallel interface in the host computer. This latter section, the host computer parallel interface, must be configured for each individual host employed. We are using a Data General MV/6000 minicomputer as our host machine. We are therefore using a Data General 4040 interface module configured for our standard communications protocol for transmitting and receiving data between the RDAS and the host computer's DMA channel. Our standard communications protocol is shown in Fig. 6. It consists of two 16-bit parallel interfaces with a data strobe output and a ready signal input. One 16-bit interface is used for data input and the other for data output.

BUS ARBITRATION LOGIC MODEL

The internal bus arbitration system used by the RDAS is double tiered. It is a combination arbiter with two inputs of different priorities and a token ring network. The physiological A/D subsystem always has the first priority to the RDAS bus. If there is physiological data available, bus control will be passed to the physiological A/D subsystem upon completion of the bus's current task. Thus, the first and highest priority input to the RDAS bus access arbiter is from the physiological A/D subsystem.

All of the gamma camera A/D subsystems have an equal priority which is of lower priority than the physiological A/D subsystem. The gamma camera A/D subsystem's bus access scheme is arranged as a token ring. The token is passed from one gamma camera A/D subsystem to the next by way of a 10-MHz clock. If the subsystem where the token is presently

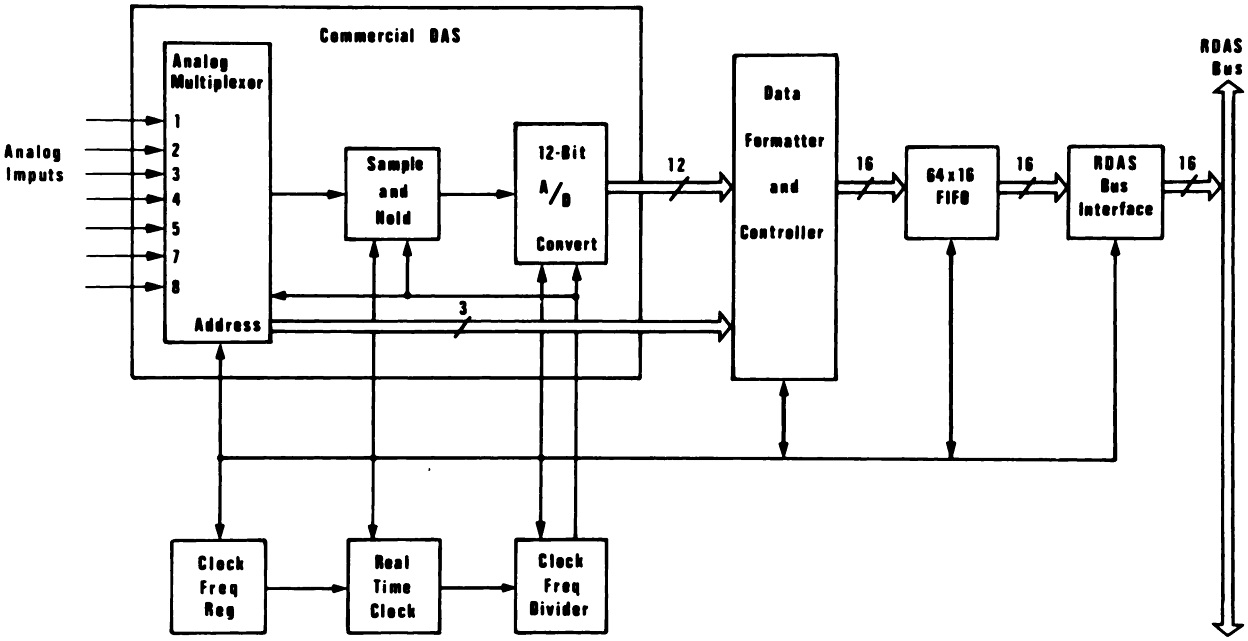

FIGURE 5
Physiological A/D subsystem block diagram

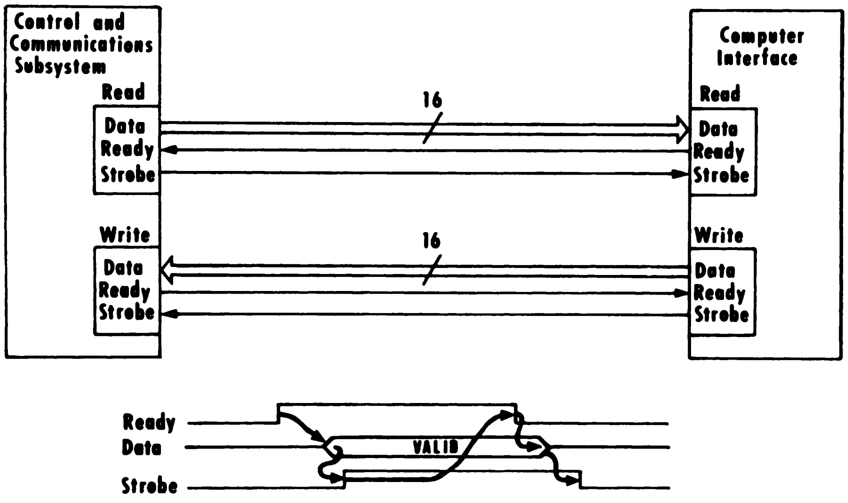

FIGURE 6
Communications protocol between RDAS Control and Communications Module and computer interface

located has data to pass to the RDAS bus, then it will be given access to the bus arbiter. Upon completion of the data transfer, the token will be passed to the next gamma camera A/D subsystem on the chain. If the subsystem where the token is presently located had no data to pass to the RDAS bus, then the token will be passed immediately to the next gamma camera A/D subsystem on the chain. A gamma camera A/D subsystem may transfer only one or two data words to the bus arbiter, depending on the data format selected, during any one transit of the token. Thus, the RDAS bus will never become "hung up" due to an exceptionally high input data rate from any one gamma camera channel. The bus access request output from the gamma camera A/D subsystem token ring is the second, lower priority input to the bus arbiter. In Fig. 7 we see a schematic representation of the token ring network and the arbiter.

The bus arbitration technique used by the RDAS is easily expandable. Additional data input circuits to serve other sources of data can be integrated into the RDAS bus. The data from these additional input modules could be treated either as high priority data (i.e., physiological signals) or low priority data (i.e., gamma camera signals). An example of an input module that could be incorporated in the RDAS is a nuclear counter subsystem. Such a subsystem, as described by Hack et al. (*6*), would provide a means of incorporating nuclear count data from a probe system directly into the RDAS data stream.

Thus, the two tiered bus arbitration logic of the control and communications subsystem provides contention-free access to the internal bus by all of the A/D subsystems included in the RDAS. The bus arbitration system also provides for future expansion of the RDAS to provide computer acquisition of data not presently supported by the RDAS hardware.

SOFTWARE

We have developed a set of low level software primitives and two acquisition software packages to permit us to acquire gamma event data in frame mode and to acquire gamma event data and physiological data in list mode. The low level primitives are tailored to our Data General MV/6000 computer system. However, the primitives are called through FORTRAN subroutine calls. Therefore, our FORTRAN 77

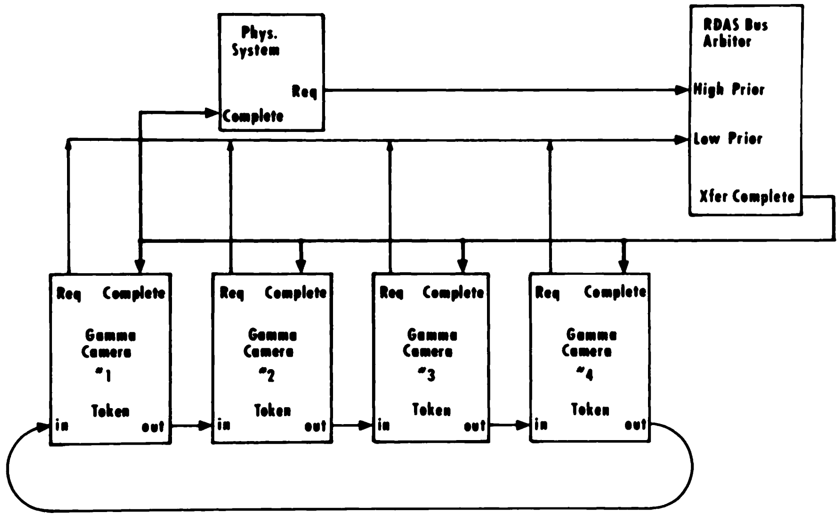

FIGURE 7
RDAS bus arbitration system block diagram

based application software that calls our primitives should be transportable to most computer systems without major modification. The primitives will have to be altered depending upon the computer system and the RDAS interface used.

Our software design philosophy is based on the following protocol for acquiring data from the RDAS. First, an initialization routine, called ADINIT, is invoked to allocate the appropriate DMA data channels and to initialize the RDAS. Second, routines specific to the initialization of the gamma camera channels and the physiological channels, called CAL-CAM and CAL-PHYS, respectively, are invoked to set initialization parameters for the input channels. These routines are called once for each channel used and initialize such parameters as A/D gain to values passed to the subroutines. Third, a subroutine to begin data acquisition, called AD-BEGIN, is invoked. At this point, it is up to the application software to provide memory buffers into which the RDAS data will be transferred and to process or store the data in these buffers once they are filled. This process is accomplished by invoking the subroutine READ-BUF multiple times. The application software passes the address of a memory buffer (a FORTRAN array) and the size of the buffer to this subroutine. The READ-BUF subroutine initiates the DMA of the RDAS data to the memory buffer specified and returns control to the calling program after the entire buffer has been filled. The application software must process or store the data in the memory buffer and then invoke READ-BUF repeatedly until the required amount of data has been collected. Finally, the subroutine ADTERM must be invoked to disable the RDAS and to clear its associated DMA channels.

Our two data acquisition application packages follow the above protocol as follows. For the frame mode application, a double buffering scheme is used. While one buffer is being filled with RDAS data through direct memory access, the data in the second are framed to a frame buffer. Once the first memory buffer is filled, the two buffers are logically swapped and the process is repeated. The time limiting factor for this multitasking scheme is one buffer must be framed in less time than it takes to fill the other buffer through DMA. For the example of an aggregate input data rate of 50 kilosamples/sec from the RDAS, the CPU time required to frame each sample must be < 20 μsec.

A double buffering scheme is also used for our list mode application. This multitasking program stores the contents of one buffer to a disk file while the other buffer is being filled with RDAS data through direct memory access. When this second memory buffer is filled, the two buffers are logically swapped and the process is repeated. The limiting factor for the list mode software is the actual disk write throughput. Since both the RDAS data acquisition and the disk writing process are handled concurrently through direct memory access, very little CPU time is used by this list mode software. In addition, to meet the timing limitations of the system, the minimum disk write time must be approximately the same as the RDAS input time per sample. For a MUGA study collecting 20,000 gamma events per sec for a total of 500,000 events, the RDAS input rate is 40 kbytes/sec, assuming 7-bits/sample, and the total disk storage requirement is one megabyte. If ECG data sampled at 500 12-bit words per second, were also added to the temporal sequence of input data in order to provide *a posteriori* gating, the aggregate input data rate is increased by 2.5% to 41 kbytes per second with a storage requirement increase of 2.5% to 1.025 megabytes. These requirements are well within the performance limitations of modern minicomputers by a factor of at least tenfold.

Although the RDAS is expandable to accommodate multiple gamma camera inputs, it was not initially intended to be used to acquire multiple independent studies simultaneously. The multiple gamma camera input capability was provided to permit researchers to employ multiple camera systems for the same study. Two examples of this configuration would be a dual headed system for SPECT or a side-by-side camera system for providing whole-body concurrent scanning. The RDAS could be used for multiple study acquisition by incorporating the concept of a "RDAS server" into the multitasking acquisition software. This "RDAS server" could acquire the temporal data stream, parse the data by channel number, and pass the appropriate channel data to requesting application software processes through intertask communications. Although this concept is intriguing, the authors have no plans of implementing such a scheme.

ACCEPTANCE TESTING

Acceptance testing of the RDAS was based on analyzing the timing of the bus arbiter, the linearity of the physiological A/D subsystem, and the linearity of the gamma camera A/D subsystem. The bus arbiter's timing characteristics were assessed by inputting simulated Z-pulses into the gamma camera A/D subsystem and operating the physiological subsystem's real time clock at various frequencies. The output stream of the RDAS was then analyzed to ascertain the number of Z-pulse events that occurred between each real time clock "tick." For example, if the Z-pulse simulator were running at 30 kHz and the real time clock at 1 kHz, one would expect the pattern of the output stream to be one physiological subsystem event followed by 30 gamma camera events. The Z-pulse simulator frequency was set for 10 kHz, 20 kHz, 30 kHz, and 50 kHz. The real time clock frequency was set for 100 Hz, 1 kHz, and 10 kHz. A total of 1,048,576 (1 M) points were collected for each experiment. The results of these experiments yielded a deviation from the expected output pattern of no more than one data point for all timing sequences.

The linearity of the physiological A/D subsystem was analyzed by inputting voltage ramps at various frequencies into the A/D subsystem and operating the real time clock at various frequencies. Regression analysis was then performed on the output data stream to quantify any deviation from the expected ramp function. The signal generator providing the ramp function was operated at 1 Hz, 20 Hz, and 100 Hz. The real time clock frequency was set to 500 Hz, 1 kHz, 5 kHz, and 10 kHz. The correlation coefficients obtained by the regression analysis exceeded 0.99 in all cases.

Two sets of experiments were performed on the gamma camera A/D subsystem to assess its linearity characteristics. The first experiment consisted of inputting an electrical ramp function into the X- and Y-inputs while a simulated steam of Z-pulses were input to the Z-input. The ramp function frequencies used were 500 Hz, 1 kHz, and 5 kHz and the Z-pulse simulator frequency was set for 25 kHz, 50 kHz, and 100 kHz. The output data were analyzed using regression analysis to determine its deviation from a ramp signal. The correlation coefficients obtained exceeded 0.99 in all cases.

The second experiment performed to assess the gamma camera A/D subsystem linearity was the comparison of flood images collected from the same gamma camera by both the RDAS and a GE Star[†] computer system. The output of an Elscint Dymax LF[‡] gamma camera was connected first to the RDAS and then to a GE Star computer system. A total of 12 million counts of flood data were collected by each system. The intrinsic flood-field uniformity parameters of Integral Uniformity (I.U.) and Differential Uniformity (D.U.) were computed from the resultant flood images according to the NEMA standards as described by Raff and Muehllehner (*7*, *8*). Briefly, the central field-of-view (CFOV) of each smoothed 64 × 64 image was first located by radially searching for the area bound by 75% of the full width half maximum (FWHM) radius of each image. The FWHM radius is defined by Raff et al. (*7*) as the radius of a circular region centered about the centroid of the flood image which contains pixels whose values are all greater than half of the value of the single pixel within the image containing the maximum amplitude. The I.U. was then calculated for each flood image based on the minimum and maximum counts within the CFOV. The D.U. was calculated based on the maximum and minimum count deviation within a six pixel range along any row or column within the CFOV. Both the I.U. and the D.U. are expressed as percentages. For the 12 million count floods acquired, the I.U. and D.U. as acquired by the Star computer were 12.6% and 9.0%, respectively. When the same 12 million count flood image was acquired by the RDAS interfaced to a Data General MV/6000 computer, the resultant I.U. and D.U. were 13.9% and 7.9%, respectively.

These results indicate that the RDAS performs as specified in the areas of the bus arbiter timing, the physiological A/D subsystem linearity, and the gamma camera A/D subsystem linearity. In addition, the intrinsic flood-field uniformity measurements calculated on similar data acquired by both the RDAS/MV/6000 system and a GE Star computer system were comparable.

DISCUSSION

A Research Data Acquisition System has been designed, implemented, and tested to permit simultaneous computer acquisition of high count rate gamma camera events and multiple signals from a variety of physiological transducers. The data obtained by the RDAS are merged into a single output stream in which data are positioned temporally. Data from up to four gamma cameras may be acquired by the RDAS at a maximum throughput of 200 kHz per input channel. The converted format of the gamma camera data is user selectable as 7- or 12-bits resolution. Data from any physiological transducer systems can be acquired by the RDAS simultaneously with the gamma camera inputs. Up to eight channels of physiological data are available with an aggregate throughput of 50 kHz. The converted format of the physiological signals is user selectable as 7- or 12-bits resolution.

The RDAS is a "stand alone" system requiring computer system dependent circuitry only in the actual computer interface. The communications links and protocol used between the RDAS and the computer interface are standard unidirectional parallel lines with 2-wire handshake signals for both the input and the output signals. The central controlling element of the RDAS is the control and communications module which merges the outputs of the gamma camera A/D subsystems and the physiological signal A/D subsystem into a single, error free output data stream. The priority scheme used by the control and communications module gives highest priority to data output by the physiological A/D subsystem and gives second priority to data output by all of the gamma camera A/D subsystems on an equal, round robin basis.

All of the following design goals were met by the RDAS: (a) to design and implement a stand-alone data acquisition system capable of interfacing to a large range of computer systems; (b) to provide multiple data input streams from physiological as well as gamma camera sources; (c) to merge the multiple data input streams into a single output stream in which data are positioned temporally; (d) to include flexible data formatting schemes that are user selected; and (e) to provide software controlled, hardware implemented gain and offset adjustments for all gamma camera signal inputs. In addition the performance of the system in the areas of timing and linearity have been found to be adequate.

The resources required to design, construct, debug, and test our RDAS, which presently contains one gamma camera channel and eight physiological signal channels, were as follows. The initial design required ~ 500 hr, the construction required an additional 200 hr, and the debugging phase required about 200 hr. The final testing was performed in 40 hr. The cost for parts was ~ $3,500 excluding the computer interface circuit board. Circuit schematics will be made available to interested researchers by arrangement with the authors.

The Research Data Acquisition System has been added to our Physiological Imaging Laboratory. It is used regularly and successfully for the simultaneous acquisition of scintigraphic images and physiological parameter signals.

FOOTNOTES

[*] Data General Corporation, Westboro, MA.

[†] General Electric Company, Medical Systems Division, Milwaukee, WI.

[‡] Elscint, Inc., Haifa, Israel.

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