INSTRUMENTATION

Low Data Loss Acquisition from a Gamma Camera with Subsequent Computer Analysis

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Magnetic tapes generated on unbuffered gamma-camera data-acquisition systems are not optimally suited for subsequent computer analysis because of data lost during the writing of inter-record gaps. This loss is particularly detrimental in dynamic and gated equilibrium cardiac studies.

We present an algorithm that avoids such losses during the reading of magnetic-tape data into a minicomputer analysis system. A set of programs built around the algorithm is used to acquire dynamic and gated cardiac studies.

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Gamma-camera data-acquisition systems (GCDAS) used strictly for data acquisition and playback without analytical functions are usually based on mass storage on magnetic tape without internal buffering. Such systems store counts serially on magnetic tape and lose counts rather than retain them in a buffer memory if there is an interruption in the data output to tape. This paper will attempt to define some of the problems inherent in a typical unbuffered GCDAS, and will describe a method of data collection that allows subsequent computer analysis without loss of data.

The data-acquisition device. The data-acquisition system used* (unbuffered) was directly interfaced to a scintillation camera†, allowing data to be placed on nine-track magnetic tape. Physiologic markers, such as cardiac gate pulses, are placed on the tape as fictitious counts at the x,y coordinates 0, 128. Each coordinate corresponds to one byte (eight binary digits). Cardiac gate pulses are generated at the 50% point of the leading edge of the R wave.

The magnetic-tape format of the storage-and-retrieval system (Fig. 1) indicates a lack of buffering. Data are transferred to tape as count events are detected, and zeros are stored on tape if no count occurs during a write cycle. Whenever an inter-record gap (IRG) is written, data and physiologic markers are lost. For 4K-byte blocks of data, the IRGs cover about 10% of the tape, and thus about 10% of the data and markers are lost.

As an example of how the lack of buffering may have a detrimental effect on data analysis, consider a gated cardiac acquisition (Fig. 2). The bars representing inter-record gaps are superimposed on an ECG trace. All data are lost during the IRG intervals. When an R-wave marker occurs during an IRG, two cardiac cycles will be combined into one and, depending on the rejection technique used, one or both of these cycles must be rejected. This results in a 10–20% average data loss. In addition to this accountable loss there is a random obliteration of data between R-wave markers. Approximately 10% of the remaining data are lost in this way. Acquisition during the relatively short end-diastolic (ED) and end-systolic (ES) intervals can thus be seriously impaired. The use of larger block sizes will somewhat reduce the chances of losing data, but the definitive solution requires complete elimination of IRGs. Tapes generated without IRGs will be referred to as unformatted tapes. IRGs may be suppressed on the storage-and-retrieval system by throwing a front-panel switch, but a compatibility problem occurs when an attempt is made to read unformatted tapes into a minicomputer.

The data-analysis system. Our data-analysis facility consists of a minicomputer‡ with 32K words of core. RT11/Gamma-11 is used as the principal operating and analysis software. Magnetic tapes generated off-line on the GCDAS are read and reformulated as patient files compatible with Gamma-11. The computer tape system|| is a nine-track, 800-byte per inch (BPI) equivalent of a DEC TM11.

Commercially available tape systems for minicomputers are designed to read data in the form of records or blocks. The size of the data blocks is adjustable, but they must be separated by inter-record gaps of standard length. Because of the limited size of core memories, unformatted (infinite block size) tapes cannot be read with standard magnetic-tape software.

In an attempt to solve this problem, an assembly-language subroutine was developed. This subroutine reads unformatted tape in sections, or pseudo blocks, of any length without requiring hardware changes in the tape drive or controller. The subroutine was written in Macro-11, the assembly language for the PDP-11.

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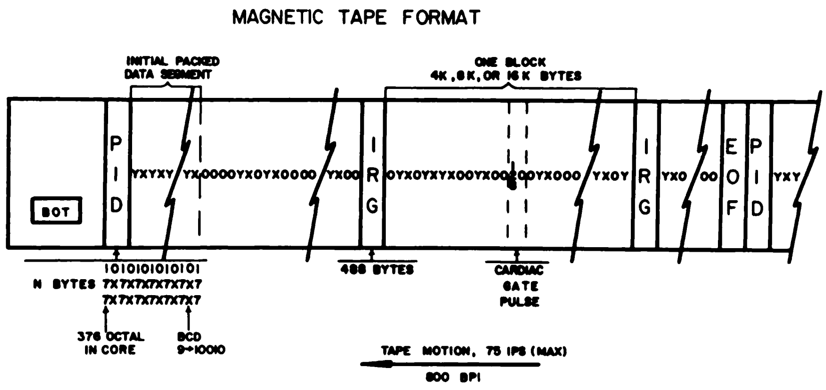

FIG. 1. Starting from beginning of tape (BOT) mark and proceeding from left to right: patient identification number (PID) is followed by Y,X coordinate pairs interspersed with zeros indicating no data. Inter-record gaps (IRG) are placed on tape at distances determined by the chosen block size. End of file (EOF) marks indicate end of patient file and are followed by next patient ID. Maximum tape speed is 75 in. per second (IPS) and data density is 800 bytes per inch (BPI).

The algorithm. In order to read short segments of an unformatted tape, the tape unit must be halted after the required number of bytes are transferred to core memory. In the process of halting, unread tape passes by the read heads of the tape drive. To prevent data loss, the unread tape must then be repositioned and read in the next pass. The repositioning itself is accompanied by an uncertainty in the final tape position, and therefore a data comparison must be made so that the new data start where the previous data left off (Fig. 3). After the first pseudo block is read and the tape unit halted, a space-reverse operation is executed to reposition old data over the tape read heads. The tape unit is then halted and as the second pseudo block is read, a matching routine compares the last 100 bytes of the first block with the corresponding bytes of the second block. If no match is found, an error flag is set. Conversely, if the match is successful the calling program is notified where the new data begin.

Since the count distribution over the x-y plane of the image is a slowly varying function of position, and since the time distribution of counts at any point on the x-y plane is Poissonian, the time distribution of coordinates may be considered approximately uniform—at least for a small area of the image. The count coordinates for this area will therefore be placed on tape in fairly random order, reducing the likelihood of accidental matching of two noncongruent 100-byte sections of tape to a very low probability.

The above argument applies if the count rate is high enough for an appreciable number of counts to be collected in a given pseudo block of tape. However, even when there are only two bytes of data (one count) in the matching region, and we assume the time distribution of coordinates to be uniform for only one tenth of the image area, the probability of a false match is low ($\sim 10^{-7}$). Furthermore, this value falls off rapidly as more counts are added, so that in any situation of interest (five or more counts in the region) the probability of an erroneous match is exceedingly low ($\leq \sim 10^{-30}$).

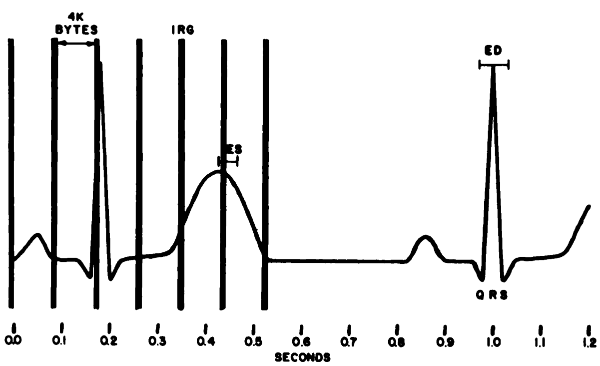

FIG. 2. Illustrating data loss due to inter-record gaps occurring during gated cardiac acquisition.

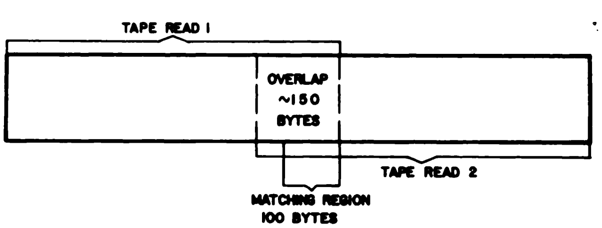

FIG. 3. Schema of algorithm for reading of unformatted tape.

Implementation of the algorithm. A flow chart (Fig. 4) for the unformatted magnetic-tape read algorithm is annotated for use with a DEC TM11EA, TU10W tape system, but may be used with most tape systems that have the equivalent of a power-clear command and a space-reverse command. These commands are necessary to halt the tape transport at any time and to reverse tape motion. Note that not all tape transports are capable of being halted before reaching an IRG.

When the routine is entered, the ready bit in the magnetic-tape command register (MTC) is tested. Next, the byte record counter (MTBRC) is set to the negative of the number of bytes to be read, and the current memory address (MTCMA) is set equal to the address of the core buffer. A read command is executed, during which the program loops, checking first if the number of bytes requested have been read (MTBRC $\geq$ 0), and second if an error has occurred. Once the MTBRC becomes zero or greater, a power clear is initiated, resulting in a hard reset of the entire tape controller, halting the tape. A wait toop is entered to assure normal completion of the power-clear operation, and a space reverse executed. A second wait loop is entered to allow the tape to return to the old data. When the tape is positioned properly over the previous data, a second power clear halts the unit. The previously described data-matching operation is performed and control is then returned to the calling program.

The subroutine returns the values of pointers to the beginning of new data, to the end of data, and the value of an error word (integer). Parity errors, bad-tape errors, cyclical

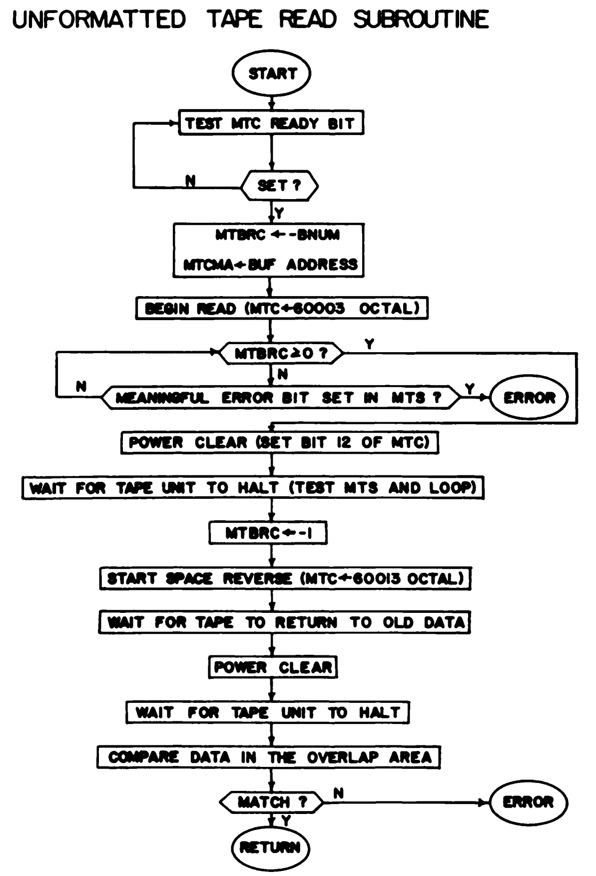

FIG. 4. Flow chart of subroutine to read unformatted magnetic tape.

redundancy errors, and record-length errors are not considered meaningful because of the nature of the unformatted read.

RESULTS

Using the above described subroutine, we have been able to acquire and analyze dynamic and gated cardiac studies using a GCDAS in conjunction with a PDP 11/40 computer. Data-acquisition programs were written to replace the corresponding Gamma-11 programs, whereas the Gamma-11 analysis programs were kept intact. The greatest benefit of these methods was in the acquisition of multiple-image gated cardiac studies. The acquisition programs use standard techniques for dividing the R-to-R interval into 20 frames (*1–3*).

The only noticeable drawback of the procedure is the extra time required to read taped data into the computer. A slightly altered version of the original subroutine is now used; it reduces this time by allowing processing of the data during the tape-to-core memory transfer.

FOOTNOTES

* Ohio Nuclear Series 75 Storage and Retrieval System, Solon, OH.

† Ohio Nuclear Series 100, Solon, OH.

‡ PDP-11/40, Digital Equipment Corp., Maynard, MA.

|| Digi-Data Corp., Jessup, MD.

ACKNOWLEDGMENT

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