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SLAC SPIRAL READER SYSTEM*

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ABSTRACT

The spiral reader is a semiautomatic film digitizing machine developed by the Alvarez Physics Group at the Lawrence Radiation Laboratory at Berkeley. It is used to measure photographs of elementary nuclear particle interactions which are created in a hydrogen bubble chamber. The entire man-machine-computer has proven to be accurate and reliable on the digitization. [1,2,3,4]

At Stanford Linear Accelerator Center (SLAC) a modified spiral reader was built to measure bigger areas, and to handle different film formats. A PDP-9 computer was selected to control and to acquire data. Practically every I/O feature on the PDP-9 was used to minimize external electronic interface and to make the control program more efficient. The PDP-9 computer performs the following functions: It guides the operator through the measuring sequence and types out warning messages on the teletype if the operator makes an error. It passes the digitized data through the DMA channel to magnetic tape, and displays the data on the storage scope. It keeps track of the stage positions and the periscope position through the add-to-memory feature. It monitors the spiral reader for any electrical or mechanical malfunction. It checks operator's efficiency and performs bookkeeping on events measured and events rejected, etc.

The entire spiral reader system at SLAC is in operation, and it is capable of producing over 70 events per hour.

INTRODUCTION

The spiral reader is a semiautomatic film digitizing machine which is used to measure photographs of elementary nuclear particle interactions created in a hydrogen bubble chamber. The entire spiral reader system is a man-machine-computer system, where man plays the most important role. The communication between the man and the machine (spiral reader) is through the computer. The function performed by each subsystem is described in the following paragraphs.

The spiral reader is a measuring machine whose design was based on the fact that the particle tracks associated with an event appear to radiate from a central point of origin called the vertex. Once centered on the vertex of an event, the spiral reader scans the film along a spiral path starting at the vertex. A pulse is generated each time the spiral reader scans over a track. The pulse then goes through a pulse height discriminating circuit for processing. If the pulse has sufficient height and sufficient width it will be passed. Also the radial and angular information for this corresponding pulse will be made available. Thus, any track or spot on the film that intersects the spiral scan is digitized into polar coordinates relative to the vertex center. In this manner, the spiral reader digitizes the entire picture independent of the number of tracks there are in the picture. The spiral reader can be thought of as a vertex-oriented measuring machine.

Before the digitized data can be used to compute the space reconstruction of an event, it is necessary to filter out the data pertaining to the unwanted tracks. To extract the desired data points a filtering program "POOH" is used. The filtering program utilizes the fact that the event tracks start from zero radius and are arcs of circles. The technique for determining the desired track points is by histogramming the region of small radius. Once a track is roughly determined in this manner, relatively simple curve fitting criteria can be used to extract the remaining length of the track. The histogramming technique is inadequate in cases of very short tracks. Consequently additional data called "crutch points" must be supplied to aid the filtering program in filtering short and/or confusing tracks.

The computer performs several functions to help man to speed up the entire event measuring process. The type of functions that are performed by the computer are: controlling the measuring sequence, fiducial centering, vertex-centering, data acquisition, data display, data storing on magnetic tape, film advancing, keeping track of events measured and events rejected, and monitoring the state of the spiral reader for malfunctions. Furthermore, the computer communicates with the human operator through the teletype/keyboard and/or console buttons.

Last of all, the human operator makes the final adjustment before any measurement is made, or decides the event is not measurable and therefore rejects the event. In cases of mechanical and/or computer failure, he has to make the final decision as to what to do.

HARDWARE SYSTEM DESIGN

Design Philosophy

The hardware system that will be discussed in this report will only cover the computer and its interface electronics. The optical and the mechanical system for the spiral reader will be described in a separate report.

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Also the detailed description of the PDP-9 computer, which is given in the "PDP-9 User's Reference Manual" will not be presented here.

Since there is a computer completely devoted to the spiral reader, it is quite obvious that one should make the most use from this computer. All the control functions should be implemented with the minimum amount of electronic hardware, thus making the interface hardware simple to design and easy to maintain. The interface design should take advantage of some of the options that were purchased with the computer.

Design Specifications

(1) All electronically controlled mechanical devices should have interlock protections.

(2) All moving devices should have a manual control and a computer control mode.

(3) All devices with similar control characteristics should have identical hardware, if possible.

(4) All I/O devices interfaced to the computer must have a status register that could be easily read and/or written by the computer.

(5) All devices should take advantage of the automatic priority interrupt (API) feature of the PDP-9 computer.

(6) Implement external scalers through use of the computer whenever possible.

System Configuration

Figure 1 shows the complete computer system and its interface to the spiral reader. This hardware system configuration can be subdivided into three parts, namely: the computer and its peripheral equipment, the spiral reader control and interface logic, and the data acquisition logic. An itemized list of the peripherals and interface logic for each part is given below.

Computer and its peripherals:

(1) One PDP-9 computer with 8K of 18 bit word memory, and a memory cycle of 1 μsec.

(2) One real-time clock with 1/60 sec of resolution.

(3) One add-to-memory feature.

(4) One extended arithmetic element (EAE).

(5) Four levels of automatic priority interrupts, and four levels of software priority interupts.

(6) One program interrupt level.

(7) One programmed input/output part for external devices.

(8) One data channel with 3 μsec/word input time, and a 4 μsec/word output time.

(9) One direct memory access (DMA) channel with a 1 μsec/word input/output time.

(10) One KSR 33 teletype printer keyboard.

(11) Two Ampex TM-7,9 channel, 800 bpi IBM compatible tape recorder. An inexpensive magtape controller that is capable of performing the following functions: read, write, backspace single record, generate and detect end of file, generate and check vertical and longitudinal parity, and rewind. The controller can only operate one tape unit at a time.

Spiral reader control and interface logic:

(1) The periscope, X-stage, Y-stage, and three identical film transport position controllers are quite similar in design. All six controllers have both manual and computer mode. The manual control of the periscope is through a potentiometer; the X-Y stage through an air-supported tracking ball; and the three separate film drives through a joystick and control buttons. The computer control for all six controllers is through 6-bit velocity registers (± 32 steps), 6-bit D-A converters and summing amplifiers. All six position controllers use PMI 400 motors driven by SLAC-developed SCR triggered circuits. Each control has its own interrupt with four possible interrupt conditions. The four interrupt conditions are reference, add-to-memory data overflow, complete, and limit-switch. The position scalers for all six position controllers are in the computer memory. The encoders used are as follows: (a) The periscope uses a small Heidenhain circular encoder with 1000 lines per revolution or 64,000 over the 32 revolution total travel of the periscope. (b) The X-Y stage uses 2 Heidenhain linear encoders with 8μ line spacing. This spacing is reduced logically to 2μ in the present case, although the logic has the capability of 1μ least count. Diodes are mounted on X-Y stage for reference information. (c) The film transport controller has the capability of using Gurley optical encoders with 2,000 counts per revolution. However, presently the film positioning is accomplished through the use of diodes to detect Brenner marks on the film.

(2) One console control logic using 10 control buttons and an interrupt.

(3) One image plane digitizer (Mangiaspago) using two Gurley optical encoders with 2,000 counts per revolution, and 14 bit scalers for each encoder.

(4) One auto-fiducial control logic which uses light sensitive diodes for sensing. Interrupts are generated whenever diodes detect the transitions from light to dark.

Data acquisition logic: The spiral reader film digitization is accomplished through the use of an automatic gain control (AGC) for equalizing film background variation, and a high speed pulse discrimation logic. Both the AGC and the pulse discrimination logic are designed and built by SLAC. At present AGC is available for both dark and bright field illumination, and each one is on a single logic card. The high speed pulse detection logic was designed to detect accurately pulses as narrow as 10μsec, and the pulse height to six 6-bit accuracy. The pulse must exceed a certain threshold before it can be accepted, and likewise on the trailing edge of the pulse this same threshold must be exceeded from the peak down before the pulse is input to the computer. When this occurs four words are input to the computer: (1) Pulse height and threshold; (2) 16-bit angle count; (3) 16-bit radius count, and (4) 15-bit pulse width. These four words enter the computer memory via the Direct Memory Access Channel at 1μsec per data or 4 μsec per data point. Furthermore, two six-bit D-A converters are used to drive one Tektronix 611 storage scope for digitized data display.

SOFTWARE SYSTEM DESIGN

Design Philosophy

The type of computer control program for the spiral reader has to be a flexible one for a simple reason, because of the different film format requirements. Different film formats might require different mechanical and/or electronic changes, which undoubtedly require some software changes in the control program as well. Perhaps the word "flexible" does not specify completely the nature of the control program in terms of programming. The control program should be designed in such a way that it is easy to add and/or delete part of the program without affecting the performance of the entire control program. Furthermore, the control program should have some kind of monitoring feature which can respond to the operator's requests, and direct subprograms to perform the desired tasks.

Design Specification

(1) All operators' requests should be requested either from the teletype printer/keyboard or the console buttons.

(2) Since the response time of most of the electromechanical devices on the spiral reader are very slow compared to the computer, all I/O control routines should be interrupt driven.

(3) The control program should be designed so that it can execute several jobs and be able to monitor the progress of these jobs simultaneously via interrupts.

(4) Each I/O device should have its own interrupt handling routine.

(5) All I/O device interrupt service routines should be kept as short as possible.

(6) For those I/O devices which require lengthy computations, their interrupt service routines should request software priority interrupts to perform the computations. This way it will leave the automatic priority interrupt system free to respond to other interrupt requests.

(7) Each interrupt service routine should have a means of returning to either the interrupted routine, or back to the main control program.

(8) All I/O devices that have similar control characteristics should be programmed alike, if possible.

System Configuration

The design of the spiral reader control program "SYSTEM GENIE" is based on both the hardware and software system design specifications. Basically, System Genie can be divided into three parts: the executives, the I/O control programs, and the spiral reader support programs. Unless otherwise stated the spiral reader computer control program "SYSTEM GENIE" will be referred to as "the system."

The executives: The executive part of the system deals with answering job requests from the operator and/or from I/O devices, queuing these jobs, and then executing them in their proper order. Furthermore, it sees that the interrupts from the I/O devices get properly serviced. The executive is made up of the following routines: job supervisor, job executor, teletype job supervisor, magtape job supervisor, software priority interrupt supervisor, and program interrupt supervisor.

The purpose of having a job supervisor is to provide a means of centralizing job requests from several different sources, and storing these job requests in some orderly fashion. The function of the job executor is to provide a means of executing jobs in the order that they are stored in the job supervisor's job buffer. The system enters the wait state whenever the job executor finds that the job buffer is empty. Since the teletype is a very slow output device, while it is typing out a message, the system could have already executed several other jobs which might also have requested the teletype for service. So the teletype job supervisor is used to keep track of the current message typeout, and to store up the rest of the requests in a buffer for further processing. Similarly, since there is only one magtape controller and two magtape transports, the magtape job supervisor keeps track of which magtape is in operation and stores up other magtape job requests in a buffer for further processing. The function of the software priority interrupt supervisor is to keep track of all the I/O interrupt service routines that require lengthy computations, but cannot afford to tie up the hardware priority levels. Finally, the function of the program interrupt supervisor is to keep track of the teletype and keyboard interrupts.

The I/O control programs: The I/O control programs are programs for the PDP-9 peripherals and spiral reader controls. All the I/O control programs have one feature in common, that is, they all have an interrupt service routine and a main control routine. The main function of the interrupt service routine is to determine which subdevice made the interrupt by the masking technique.

The control programs for the PDP-9 peripherals are teletype, keyboard, realtime clock, and magtape subroutines. Teletype subroutines consist of alpha-numerical, decimal and octal output routines. Keyboard subroutines consist of alpha-numerical, decimal and octal input routines. Realtime clock subroutines consist of routines that compute the time of day and incremental time difference. Magtape subroutines consist of write N records, read N records, backspace N records, etc. routines, where N is the number of records.

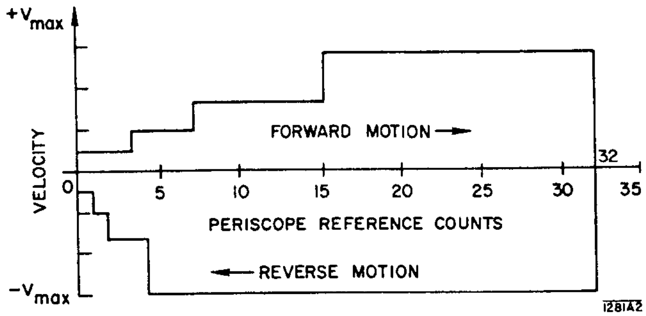
The spiral reader control programs consist of the following routines: radius and angle high-speed data channel, periscope, X-Y stage, film drive, console, image-plane-digitizer (IPD), and auto-fiducial control.

(1) The radius and angle high speed data channel routine is activated by the periscope control program. Once this routine is activated, digitized data enter the memory via the direct memory access at 4 μsec per data point. A double buffer technique is used to save memory space. The two buffers, each of size 512 words, are switched back and forth through interrupts. As soon as the first buffer is filled up, an interrupt is generated, and the second buffer is switched in. While data are entering the second buffer, the first buffer is being written onto the magtape. When the second buffer is full, an interrupt is generated and the first buffer is switched back in again. Meantime the data in the second buffer are being written onto the magtape. This process ends whenever a spiral scan is finished. On a normal scan, approximately 600 to 700 data points are recorded, and this would mean each buffer would have to be switched back and forth 3 to 4 times.

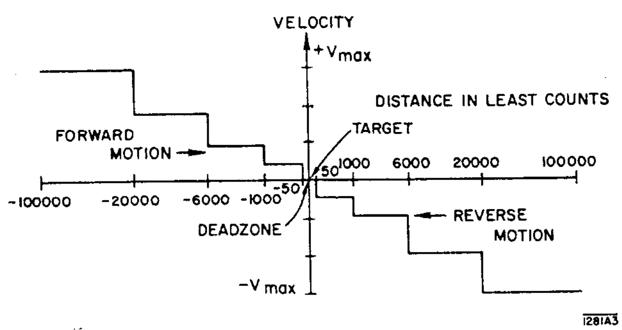
(2) The periscope position control routine uses reference interrupts generated by the Heidenhain circular encoder to control the position and velocity of the periscope. During the entire linear travel of the periscope 33 reference interrupts are generated. The periscope always sits behind the optical zero, and when the first reference interrupt is generated, the radius and angle high speed data channel are activated. The periscope velocity vs. periscope position (in terms of reference counts) in both forward and reverse direction is shown below.

(3) The X-Y stage position control routine uses the add-to-memory data overflow interrupt to control the position and speed of the stage. Actually there are two identical control programs, one for the X-stage and the

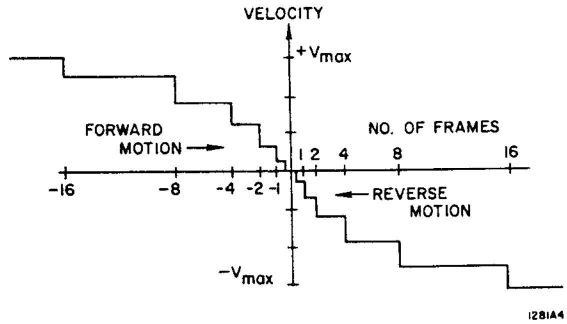
other for the Y-stage, working simultaneously. Since both X and Y have identical control programs, it is only necessary to explain how one of them works.



In order to move the stage from one position to a desired position, the first step is to compute the distance between the two positions. The next step is to place a set of predetermined zone distances at the desired position. Then the distance in which the stage must travel to reach its destination is compared with these zones. If the distance is larger than the largest zone distance, then the stage is controlled to move at its maximum velocity to the first zone boundary. From then on, the stage is controlled to move to each zone boundary with the corresponding velocity until it has reached its destination. If the initial distance lies inside one of the boundaries, then the stage is controlled to move to the next zone boundary at the corresponding velocity. For the rest of the distance, the stage is controlled in the same manner as the previous case. In order to get an add-to-memory overflow interrupt at each of the zone boundaries, the initial stage position in the scaler is stored away, and the difference between the largest number (377777_8 or 400000_8) and the distance to be traveled is computed and stored in the scaler. Since the initial stage position is stored away, that position has to be updated accordingly each time a zone boundary is crossed. Only until the final destination is reached, the updated stage position is restored back into the scaler, and the scaler should read the desired position. The stage velocity vs. stage position (in terms of least counts) is given below.



(4) The film drive control program uses reference interrupts to control the position and velocity of the film. A reference interrupt is generated every time a Brenner mark on the film is detected by the diode which is mounted on the film platen. The distance between the Brenner mark and the center of the picture is fixed, so the problem of film advancing and stopping on the right frame number becomes a problem of simply counting the number of Brenner marks and then stopping. The velocity of the film drive is programmed according to the number of frames away from the desired frame number. The velocity vs. the number of frames for both advancing and reversing is shown below.



(5) The console control program is activated every time one of the console buttons is pushed. The interrupt service routine reads and masks the status to decide which button generated the interrupt, and then executes the corresponding routine. Each console button performs a specific job, and the jobs are: view change via stage movement, fiducial measurement, vertex measurement, IPD measurement, crutch-point measurement, flagged crutch-point measurement, event rejection, and advance to next event/view/frame. The console buttons are program interlocked, that is, each button can be enabled or disabled individually by programming. During the normal operation only the view select button is enabled, and the rest of the buttons are disabled. The rest of the buttons are individually enabled whenever they are needed in the event measurement sequence.

(6) The image plane digitizer (IPD) program consists of routines that read, store, and write IPD data onto the magtape.

(7) The auto-fiducial control program has not been implemented yet.

Spiral reader support programs: The spiral reader support programs consist of the following routines: manual fiducial measurement routines, vertex measurement routines, MRQ (Measurement Request Tape) routines, flagged crutch-point routines, system recovery routines, and the main spiral reader event measurement sequence.

The manual fiducial measurement routines consist of routines that allow the operator to measure fiducials, move stage to fiducials, and check fiducial measurements.

The vertex measurement routines consist of routines that compute vertex positions in all three views, move stages to vertex, handle multi-vertex and multi-event situations, and allow the operator to measure the vertex and start the spiral scan.

The MRQ routines consist of routines that allow the operator to search the magtape which contains the scan information on any roll, frame, and beam track number of an event.

The flagged crutch-point routine allows the operator to measure crutch points and at the same time makes the system remember those points for the successive two views. The manner in which this is accomplished is that the operator has to measure the crutch points manually, say in view 2, then after each spiral scan in view 1 the system will automatically move the stage to where it thinks the crutch point should be, and then it will let the operator perform the final adjustment. The same process is repeated for view 3.

The system recovery routines consist of routines that allow the operator to recover from any errors while typing information on the teletype, permit the operator to back-up the magtapes to measure certain events over again, and also allow the operator to reject any event for certain reasons.

The main spiral reader event measurement sequence is a routine that calls all the routines mentioned above in some specified order.

CONCLUSION

The SLAC spiral reader system has been in operation for several months now. Presently, there are still a number of tests being done on it in order to determine its accuracy, repeatability, and long-term stability of the entire system. So far, all the results that we are getting indicate the spiral reader can become a useful physics tool. Currently, with beginner operators, we can achieve a measuring rate well over 70 events per hour.

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Fred Martin	Mark Jensen
Benjamin Shen	Russell Matheson

Programming	Mechanical
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Robert Good	Ronald Cochran
Michael Hu	Charles Hoard

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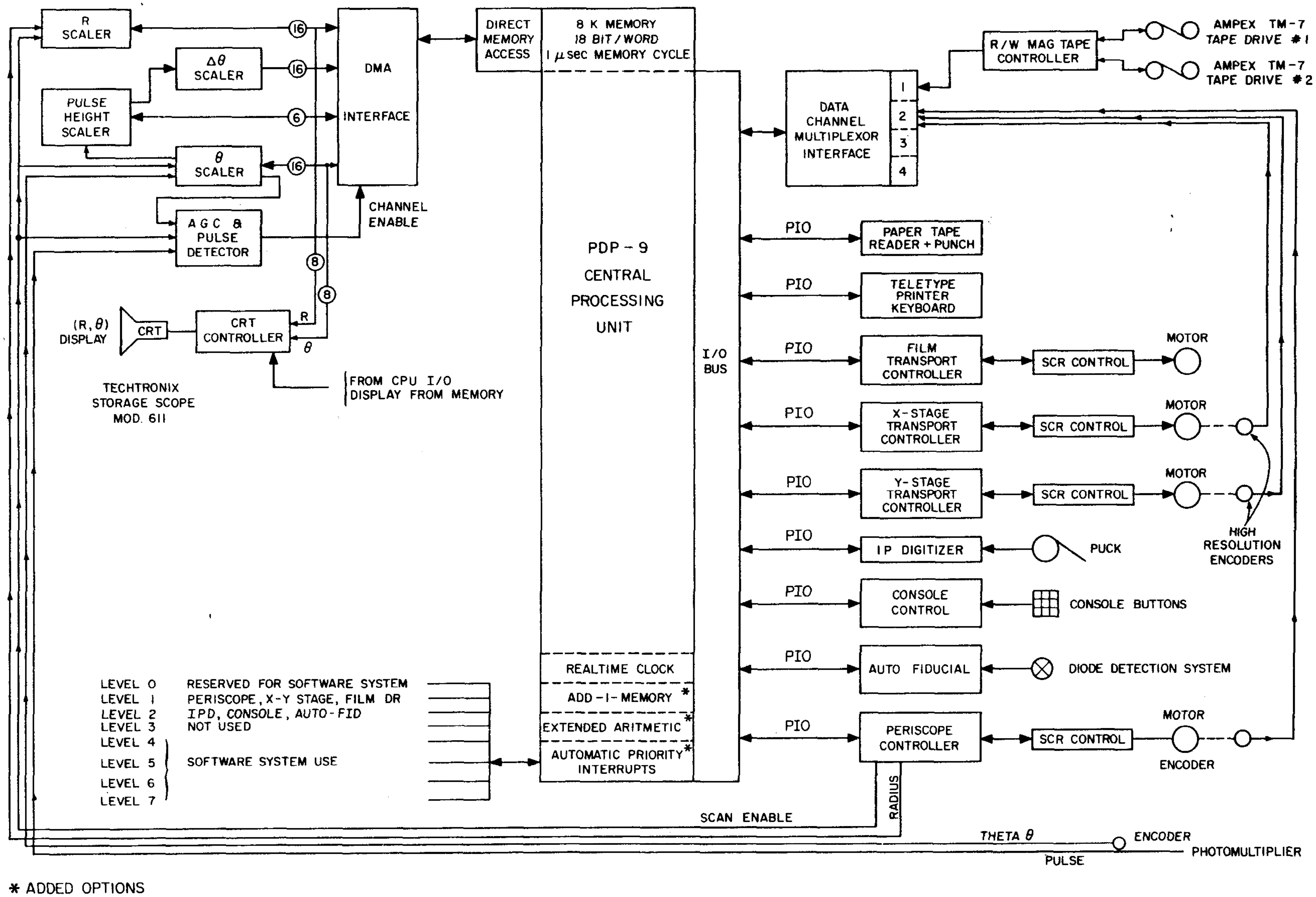

SPIRAL READER COMPUTER CONTROL SYSTEM

Fig. 1