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MASTER

DATA ACQUISITION FOR PLT*

Philip A. Thompson
Princeton Plasma Physics Laboratory
Princeton, NJ 08540

ABSTRACT

DA/PLT, the data acquisition system for the Princeton Large Torus (PLT) fusion research device, consists of a PDP-10 host computer, five satellite PDP-11s connected to the host by a special high-speed interface, miscellaneous other minicomputers and commercially supplied instruments, and much PPPL produced hardware. The software consists of the standard PDP-10 monitor with local modifications and the special systems and applications programs to customize the DA/PLT for the specific job of supporting data acquisition, analysis, display, and archiving, with concurrent off-line analysis, program development, and, in the background, general batch and timesharing.

Some details of the over-all architecture are presented, along with a status report of the different PLT experiments being supported.

PAST PPPL COMPUTERIZED DATA ACQUISITION

The first computer for the support of the major experimental devices at PPPL was installed in the summer of 1970. It consisted of an IBM-1800 similar to the one that had previously been acquired to provide monitoring and control for the FM machine. From that time to the present this system, the DAS-1800, has developed into a versatile facility which, at its peak, was supporting concurrently ST, FM, and ATC. By suitable expansion of the original hardware and continued development of both systems and applications software DAS-1800 has been able to meet the goals of presenting shot-to-shot results for guidance to the physicists in the conduct of their experiments, of providing a system that was both understandable and programmable by the physicist-user, and of assembling both the hardware and software to permit adding new experiments quickly and changing existing ones on the fly during experimental runs.

Measures of the success of the DAS-1800 system have been the ever increasing acceptance of the fact that experiments can be made easier, if not better, by the support of the computer and the near universal usage of the computer-generated display figures in papers and reports by the experimental physicists. Among the reasons for DAS-1800 being a success are the fact that the IBM-1800 computer has a vendor-supported monitor well suited to priority-ordered,

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real-time activities and an adequate subset of Fortran-IV. Thus it has been possible to maintain the DAS-1800 software with a small programming staff. In addition, the hardware supplied by the vendor was designed for easy attachment of the external "process" signals and devices. As a result of this convenient design only a small amount of locally produced hardware was necessary for initial operation of the system. Of course, with the ever increasing usage of DAS-1800, much specialized interfacing hardware has been designed and built at PPPL to permit quite sophisticated support for experimental diagnostics[1],[2].

The postscript to the DAS-1800 story will be written within the next year, for the two experimental devices now being served by this data acquisition system will have to be removed shortly to make room for PDX, the next generation in research tokamaks at PPPL. A few months after ATC and FM are no longer producing data, all post-run processing will have to come to an end so that the IBM-1800 itself can be dismantled to provide space for expansion of the PLT computer to make it adequate for supporting PDX.

PLT DATA ACQUISITION REQUIREMENTS

In determining the probable computer support that would be necessary for PLT, the past experience with DAS-1800 was the best guide, since many of the proposed diagnostic experiments were similar to those previously running on ST, FM, or ATC. In addition, it was determined early on that the mode of operation, especially as it concerned computerized data acquisition, would be essentially the same as that for ST, with the main differences being that PLT would be more highly instrumented (i.e., more concurrent diagnostics) and the design repetition rate for machine pulses would be 60 seconds at full power. (Past experience on this point, however, would indicate that a faster rep-rate at lower fields -- say 30 seconds -- would be the more popular mode of operating; thus the computer system should be configured for adequate response within this period.)

At the time when the preliminary specifications for the PLT computer system were being assembled, two experiments had already been defined in enough detail that they could be used for extrapolating from what was known on DAS-1800 to what would be required on DA/PLT. The first of these was the heavy-ion beam probe, for which there would be only a modest scale-up of complexity and increased computer control. A factor of ten times the computer support provided by DAS-1800 was deemed the appropriate level to require of DA/PLT.

The other diagnostic defined well enough for extrapolation purposes was the Thomson Scattering experiment. Here the assumed availability of appropriately expanded computer support had helped to encourage the spectroscopists to redesign their equipment to read the scattered laser light from 40 different radial positions in the plasma column, rather than only one as previously. Also, 20 Doppler-broadened wavelengths instead of only seven or eight would be recorded. Thus, even with the possibility of coding improvements, it would require at least 40 times as much computing on each shot as that which had been done for ST Thomson Scattering by DAS-1800.

Further, since PLT was to be a much more expensive machine than anything ever built at PPPL before, it was obvious that a greater premium would be placed on performing more experiments at the same time and getting back the results faster. Computer capabilities substantially enhanced over those provided by DAS-1800 were needed both for better real-time guidance in running the machine and for more cost-effective execution of the experimental program.

So at that time it was believed that the new Thomson Scattering (called TVTS, since the storage medium is actually a vidicon TV camera tube) represented the largest factor for increased power over the IBM-1800 computer that would be required from the PLT computer.* In addition, however, it was realized that there would be many more diagnostics running together at any one time than there had normally been on ST. From these facts it seemed prudent to be thinking about a computer system that would provide a 50-fold increase in CPU power over the IBM-1800, with appropriate scale-up of peripherals, memory, etc.

Feasibility and Systems Studies

Having determined that a new data acquisition facility would be necessary for PLT, PPPL submitted "Feasibility and Systems Studies" in January, 1974, to the AEC. Experience with DAS-1800 had demonstrated the feasibility of PPPL data acquisition methods. However, for large-scale data acquisition systems of the sort under discussion there are usually three approaches considered:

a) use of a remote central computer facility via "intelligent" terminals and communications lines.
b) a multiplicity of highly configured, independent minicomputers, and
c) a medium-sized host computer with simple front-ends.

Since the projected data rates were much too high for ordinary communications lines and since there was no known computer center

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*It has subsequently developed that a planned X-ray wave detecting experiment with 60 transducers would require over 10,000 times the power of an IBM-1800, if, as is desired, the calculation were done in real-time!

available which could offer reliable service for the entire two-shift per day operation of PLT, the first approach was clearly not feasible.

The other two approaches were thoroughly investigated by benchmark tests and by visits to various laboratory sites using the two different methods. The conclusions were that to meet the PLT requirements six to eight well-equipped minicomputers would be needed to take care of peak data acquisition periods plus program preparation and off-line analysis. What with duplication of peripherals and the like the total cost for an all-minicomputer system would be about the same as that for a medium-sized host with simple front-ends.

The former approach obviously provides redundancy and the independence of the minicomputers insures that the failure of one component will not keep all the rest of the system from being used. On the other hand, a medium-sized central computer can run larger programs than any combination of minicomputers and this extra power can be shared among all experiments as needed. Further, during the period when PLT would not be running, this computer power could be utilized for more extensive off-line data analysis and general purpose computing. And if this computer had time-sharing capabilities, this would be a service otherwise unavailable at that time at Princeton University. A final, more subjective impression helped to convince us that the host with front-ends approach was the better one: the software on the medium-sized computers seems to be much more highly developed and mature than that on the minicomputers.

Thus, the systems part of the "Feasibility and Systems Studies" proposed four 12 to 18 bit, 16k minicomputer front-ends to a medium-sized host computer, which, based on preliminary vendor information, would be in the DEC PDP-10, IBM 370/135, Xerox Sigma-9 class.

AEC approval was received and a line item was placed in the PPPL FY75 budget.

SPECIFYING AND SELECTING A SYSTEM

The specifications written for a system

of a medium-sized host computer with four rather simple front-end minicomputers was basically an extrapolation from the existing IBM-1800 with four PDP-8s of DAS-1800. As indicated above, the basic CPU power requirement had been established as being at about 50 times that of the IBM-1800 and a simple benchmark to test this speed ratio was given to all prospective bidders. Speed, however, was not the only criterion of interest. A capability, similar to that of the IBM-1800, of running multiple concurrent programs according to a predefined priority scheme was also required. In addition, a feature not provided by the IBM-1800 was desired: interactive terminal support.

Exact details of hardware and software architecture were not included in the specification. Rather, a complex benchmark was devised to test the suitability of a given system for providing the different capabilities in the mix required. This complex benchmark consisted of the following elements:

a) Two real-time jobs with data acquisition simulated by reading the information from magnetic tape -- one large and fast and the other small and slow -- which were run alternately every 30 seconds throughout the benchmark;
b) Two interactive terminal sessions -- one exercising text editor features and the other using on-line debugging tools to correct a doctored Fortran program -- which lasted until the end of the benchmark;
c) A background "number cruncher" program which was contrived to run the entire time and to be too large to co-exist with the "large" real-time job;
d) A continuous batch stream of all types and sizes of jobs (mostly actual jobs from the IBM-1800) to test compiler features, error handling, and the like.

The written part of the specification called for the host computer to have a main memory of at least 128k words of at least 32-bit length, disk memory of at least 20 million words, two IBM-compatible magnetic tape drives, 16 asynchronous serial lines for interactive terminals, a card reader, a line printer, a CalComp plotter, an interactive graphics unit, 32 multiplexed analog input lines with a 50kHz or better analog-to-digital converter, and miscellaneous digital input-output and external priority interrupt lines. The minicomputer part called for four units connected by a vendor-supplied high-speed parallel interface to the host computer. Each of the four units was to have 16K of memory and basic analog and digital input-output facilities. Additionally, two of the unit were to have a million-word disk and floating-point hardware so that they could be used for program preparation and the like on a stand-alone basis even if the host computer were not operating.

These specifications were sent to over a dozen vendors. At that time (Spring of 1974) only three vendors could or would respond. Digital Equipment Corp. submitted the lowest bid; also their proposal was the most responsive and they received the highest score on running the complex benchmark.

VENDOR-SUPPLIED CONFIGURATION

The major components included in the DEC bid were the following:

1) 1-KI10 processor (hardware address translation, etc.)
2) 2-MF10G memories (total 128K, 36-bit words)
3) 2-RP03 disk drives and controller

(total 20 million words)
4) 2-TU10 magnetic tape drives and controller (9-track, 800 bpi)
5) 1-LP10-H line printer (925 lpm, 96-character)
6) 1-CR10-D card reader (1000 cpm)
7) 1-DC10 line scanner (16 lines, 8 modem controllers)
8) 1-TU56 dual-DECtape drive and controller
9) 1-CalComp 565 digital X-Y plotter
10) 1-DMA10 parallel interface for up to 8-PDP-11s
11) 1-PDP-11/40, 8k memory, with
   32-channel, 50kHz, 13-bit A/D converter,
   4 50kHz, 16-bit digital input register,
   1 1kHz, 32-bit digital input register,
   1 1kHz, 32-bit digital output register,
   100 1kHz digital output points,
12) 1-GP10-L interface for 36 external priority interrupts
13) 4-KSR-33 Teletypes (110 baud)
14) 4-LA30 DECwriters (300 baud)
15) 4-VT05 CRT terminal (2400 baud)
16) 4-Tektronix 4010 Graphics display terminals (to 9600 baud)
17) 1-GT40 Interactive graphics terminal (9600 baud)
18) 1-PDP-11/40, 16k memory, system with
   hardware floating-point,
   1-million-word disk,
   dual DECtape drive,
   8-channel, 40kHz, 12-bit A/D converter,
   x-y oscilloscope driver,
   9600-baud asynchronous line driver,
   ASR-33 Teletype,
19) 1-PDP-11/40, 16k memory, system with
   hardware floating point,
   1-million-word disk,
   dual DECtape drive,
   x-y oscilloscope driver,
   9600-baud asynchronous line driver,
   ASR-33 Teletype,
20) 1-PDP-11/40, 16k memory, system with
   dual DECtape drive,
   8-channel, 40kHz, 12-bit A/D converter,
   x-y oscilloscope driver,
   9600-baud asynchronous line driver,
   ASR-33 Teletype,
21) PDP-11/40, 16k memory, system with
   dual DECtape drive,

x-y oscilloscope driver,
9600-baud asynchronous line driver,
ASR-33 Teletype.

The software included in the DEC bid consisted of the standard monitor, TOPS-10, without the special option for virtual memory (i.e., demand paging) which the KI10 processor supports. In addition to all the standard language processors and utilities, DEC also included in the bid a) FORTRAN-10, their new optimizing Fortran, b) MACY-11, the cross-assembler for PDP-11s that runs on the PDP-10, c) RT-11, a foreground/background stand-alone monitor for the PDP-11s, d) a Fortran compiler for the PDP-11s, and e) LAB-APPS, a so-called laboratory applications package supporting the special Laboratory Peripheral System of analog and digital input-output interfaces on the PDP-11s.

Details of Current System

The interface between the PDP-10 and the five PDP-11s is called a DMA10, the commercial version of a special interface that DEC built for a bubble-chamber track analyzing system at CERN. The software written by DEC which controls the DMA10 operation turned out to be much larger than expected when changed from the specific bubble-chamber reading form to a completely general purpose implementation. It was, therefore, necessary to add 32k of extra core memory (for a total of 160k) to the PDP-10 to accomodate this extra code.

Another addition to the original configuration for performance enhancement was an RS04 swapping disk. This 256k, fixed-head disk materially reduces the time necessary to swap programs in and out of core when the total amount of address space needed by all concurrent jobs is greater than the amount of physical core available. A later software addition has also improved this situation. This is the Virtual Memory option for the monitor referred to above. With this special software on the KI10 processor a program of any size up to the maximum address space of 256k can be run, albeit at reduced efficiency. The Virtual Memory software brings "pages" (512 words) of the program from the swapping disk into core as they are needed, swapping out other "pages" that are not currently being used. The operation of this "demand paging" has no effect on other programs not requiring it.

Also since this original installation of the system eight more asynchronous serial lines have been added. This brings to a total of 24 lines with baud rates of from 110 to 9600 (10 to 960 characters/second). Six of these lines are attached to modems for dial-up access to the computer from any telephone. Most of the rest of the lines are interconnected via a patching panel to so-called "hard wired" terminals in the vicinity of PLT. These terminals include eight Tektronix Model 4010 graphics display units (programmed by Tektronix-supplied software), nine CRT units for alphanumeric text, and some twenty units which produce printed output (hardcopy) and operate at either 10 or 30 characters/second.

Besides the Virtual Memory option for TOPS-10, other special software added to the system included SITBOL, a rather small and fast implementation from Stevens Institute of Technology of SNOBOL-4, and several items from the exchange library of DECUS, the DEC Users' Society. Among the latter are LISP, REDUCE (a mathematical equation manipulation language similar to FORMAC), and utilities for handling IBM-format magnetic tapes.

PPPL Additions and Modifications

It could well be claimed that the DA/PLT system represented a general design suitable for many large-scale data acquisition environments. One of the universal characteristics of such a system, however, is that customizing to the particulars of the local installation are necessary. This next section will be devoted to some of the additions and modifications made to the commercially-supplied hardware and software.

The PDP-10 is basically a powerful time-sharing system to which have been added batch processing capabilities and the "hooks" for doing real-time, experiment-related work. Hence, the concept common on smaller systems of an external signal (from an experiment, for instance) interrupting the CPU at a predetermined priority in relation to other such external signals and to the internal interrupts of of the hardware is missing from the normal PDP-10 system. The "hooks" -- in the form of the GP10 General Purpose Interface and simple Fortran-callable subroutines -- are provided. The manual for the GP10 gives straightforward instructions for constructing such an external interrupt system from standard DEC modules.

To provide parallel interfacing ports for existing minicomputers the same GP10 might be used. But, since these minicomputers have only either 12 bits (PDP-8s) or 16 bits (other PDP-11s, Nova-2s, TI-980s, etc.), a 36-bit interface was not needed. Rather, it was deemed expedient to use a standard parallel interface on one of the five PDP-11/40s. A local enhancement to this system provides for multiplexing up to eight minicomputers through one such interface.

Among other special hardware of more general interest which has been produced at PPPL for the PLT system are the transient analyzers described in another paper at this Symposium [3] and a set of 32 sample-and-hold units operated by the programmable clock of the high-speed A/D converter in the special PDP-11. With this latter arrangement data from all 32 lines is acquired at the same time, even though the analog to digital conversion is done in a sequential fashion.

The three major software projects for adapting the system as delivered by DEC to the needs of PLT were (a) DMA10 control routines (on both the PDP-10 and the PDP-11s) [4], (b) a table-driven submonitor for providing priority sequencing of all PLT tasks, and (c) a comprehensive system of display programs. This latter system consisted first of a set of subroutines to emulate the operation of the display system on the IBM-1800 so that existing programs could be quickly converted to Tektronix 4010s and the CalComp on the PDP-10. The major effort, however, was devoted to producing a system for simulating Tektronix 4010 displays on x-y storage oscilloscopes (Tektronix 601, 603, 611, 613) driven by four of the PDP-11s.

INITIAL PLT OPERATION

As this Symposium is being held (November 1975), the final preparations are being made for the start of PLT operation. Initially, data from the following diagnostics will be acquired:

1) Plasma current and loop voltage,
2) OH and SF field currents,
3) Plasma TV imaging at limiter,
4) TVTS (multi-channel Thomson Scattering),
5) 2mm microwave interferometer,
6) Beta(theta) from diamagnetic loops,
7) Plasma equilibrium position,
8) X-ray pulse-height analyzer,
9) Ion temperature from charge-exchanged neutrals,
10) Visible and UV spectrometry,
11) X-ray wave detector (2 points only),
12) Plasma stability from B(theta) loops,
13) Vessel wall analysis,
14) Fast ion-gauge pressure, and
15) Miscellaneous timer and knob settings, shot number, time, date, etc.

Among the special hardware which has been produced for these specific diagnostics are the plasma TV system based on a TI-980A minicomputer, the TVTS vidicon control and digitizer, the automatic "fringe" read-out for the microwave interferometer, and the custom-made X-ray PHA unit (containing a PDP-11/05) from Tennecomp.

Data from all of the diagnostics listed above will be handled by DA/PLT except for Plasma TV, which will have only local display capabilities for the present. For all the others a combination of automatic and interactive software -- as is most appropriate for different modes of operation -- has been prepared. Almost all raw data and results will be displayed on one of four Tektronix 4010 graphic terminals or one of six Tektronix 613 memoscopes.

In addition to acquiring, analyzing, and displaying experimental data, there is a need to save both raw data and calculated results for future consideration. In the past on the DAS-1800 system this archiving was done in an efficient manner by transfering disk data from individual diagnostics to magnetic tape on an irregular basis when disk space shortage demanded it. In response to rather recent suggestions from the experimental physicists, the archiving on DA/PLT will have another characteristic: the data will all be stored automatically in a compatible manner, so that any information from any diagnostic on any shot or shots can be retrieved by anyone. An extensive system is being developed to allow all data to be retrieved in an easy-to-interpret form and displayed in a standardized format.

Future System Expansion for PDX

Since PLT and PDX (which is scheduled to start operation in FY77) will not be able to run at the same time, one data acquisition system can, in principle, service both devices. It has been established from the manner in which PDX will operate and the diagnostics to be run on it that the computing requirements for it will be about 150% those of PLT. Besides the scale-up of the present DA/PLT system to take care of these needs, there will be necessary a further enhancement to allow acceptable use of the data system by the experimenters from the device not running on a given day to do off-line analysis, program development, experiment set-up, etc.

The expansion of the present system has been defined and scheduled to be accomplished in a two-year period in such a manner that PLT will be able to take advantage of each enhancement to meet the needs of later experiments. The following are the planned changes to the system and the scheduled dates:

1) Expand core memory to 256k (done October 1975),
2) Change disk drive to newer models having about three times the transfer rate and 40M words (December 1975),
3) Add 728k of head/track swapper (mid-FY76),
4) Add terminals and lines (FY76),
5) Upgrade the CPU (FY77),
6) Change to higher performance magnetic tape units (FY77), and
7) Add PDP-11s and interfaces (as appropriate).

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[The text for this paper was prepared on the DA/PLT DECsystem-10 by the program RUNOFF.]