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ABSTRACT

Diagnostic instruments at the Mirror Fusion Test Facility (MFTF-B) are operated by a distributed computer system which provides an integrated control, data acquisition and data processing interface to the experimentalist. Instrument control settings, operator inputs and lists of data to be acquired are combined with data acquired by instrument data recorders, to be used downstream by data processing codes; data processing programs are automatically informed of operator control and setpoint actions without operator intervention.

The MFTF-B distributed computing environment permits us to take advantage of several kinds of computing equipment and commercial software. The combined diagnostic control and results presentation interface is presented to experimentalist users by a network of high-resolution graphics workstations. Control coordination, data processing and database management are handled by a shared-memory network of 32-bit super minicomputers. Direct instrument control, data acquisition, data packaging and instrument status monitoring are performed by a network of dedicated local control microcomputers. A description of this system and our experiences in implementing the first MFTF-B diagnostic instrument, the Magnetic Field Alignment diagnostic (MFA), are reported here.

The Complete Data Acquisition Problem

At the Mirror Fusion Test Facility (MFTF-B), we approached the problem of acquiring data from MFTF-B diagnostic instruments as part of a larger problem of managing the exchange of information between a control process, an acquisition process and a data analysis process. This is illustrated in Figure 1, which shows that control, data acquisition, and data processing are linked together by a circular flow of data during repeated experimental cycles. I will call this the complete data acquisition problem.

Our objective was to reduce the amount of redundant data entry and to increase the reliability of information exchange between the different processes required to operate plasma diagnostic systems. I will describe how we have attempted to meet this objective. To put matters into perspective, there will be a short description of the overall MFTF-B computer control system and a discussion of the part devoted to plasma diagnostics. Following this, the paper details how diagnostic instruments are controlled, how data is acquired and put into our database, and how information generated during both the control and acquisition processes reaches the data analysis process and eventually the experimentalist.

The MFTF-B Computer Control System

The MFTF-B computer control system, called Supervisory Control and Diagnostics System (SCDS), is comprised of nine Perkin-Elmer 32-bit minicomputers linked together by one megabyte of shared memory. SCDS has already been well described in several references[1-4] which include an excellent graphic representation of the system. Figure 2 shows the part of SCDS hardware architecture which is allocated for plasma diagnostics; the rest of SCDS is on the other side of shared memory. Figure 2 can be divided roughly into three horizontal layers which correspond to both a tripartite hardware and a tripartite functional division.

The upper third of Figure 2 depicts plasma diagnostics workstations. These are Sun Microsystems Sun 2/170 graphics workstations which have high-resolution graphics CRTs supported by a multitasking, windowing operating system. Additional features of note are the built-in networking support (Ethernet and DARPA TCP/IP), graphics support (a version of Core), and accessible menuing. The workstations are well suited to user interface presentation, and this, indeed, is the functional responsibility assigned to them. The graphics capability permits sophisticated presentation and manipulation of results. For example, interesting parts of graphs can be zoomed and points can be scaled using a mouse-driven crosshairs. The windowing capability permits connection (via network) to tasks running in the minicomputer which are directly involved in diagnostic operation. Window management and menuing allow an operator to select and dispose graphics and control windows in convenient juxtaposition.

The workstations remove the burden of formatting and managing the user interface from the middle third of Figure 2, the Diagnostic Data Processor (DDP1). DDP1 is one of the nine 32-bit Perkin-Elmer minicomputers (specifically a 3250) and is characterized by a wide, high-bandwidth bus, large DMA bandwidth, fast floating point and a multitasking, real-time distributed operating system[4]. Because of its nonagonal position and its capacity to handle peripheral devices, DDP1 would be wasted pushing bytes to manage a user interface or to control diagnostic hardware directly. Instead, this machine performs coordination between diagnostic instruments and the rest of SCDS, manages our database, makes control policy decisions based upon a simple control language, and processes acquired diagnostic data to provide results. The software structure which implements this can be described as an hierarchical arrangement of message-passing tasks. How these tasks interact will be discussed later.

The actual control, monitoring, and hardware data acquisition is performed by the equipment shown by the lower third of Figure 2. Local Control Computers (LCCs), usually DEC LSI-11 microcomputers, run a small executive program called PLEX[5-7] which typically controls and monitors modules in CAMAC instrumentation. LCCs are inexpensive and are eminently good "byte bashers", which makes them ideal to fill a low-level niche in our system hierarchy. PLEX interprets standardized device commands sent by the supervising DDP, using a device configuration database[8], to control or set equipment, including digital data recorders. PLEX polls device registers, usually in CAMAC modules, and reports "significant" changes to higher supervisory levels. Perhaps most important from the standpoint of data acquisition efficiency, LCCs package (byte-swap, convert, name, tag, packetize) data collected from CAMAC data recorders and send it neatly to the Diagnostic Data Processor. One LSI-11 is not so much, but many working in parallel can be formidable.

Software Structure

Software ties this network of disparate equipment together into a coordinated system. MFTF-B diagnostic software is structured as a group of message-passing tasks which execute in the distributed, shared-memory environment. An hierarchical command structure is imposed upon the grouping by conventions and protocols for messages. These conventions and protocols have been extended to the networked graphics workstations so that, logically, there appears to be one environment, subject to some unavoidable deviations due to differences in operating systems. Figure 3 is a simplified data flow model of MFTB-B plasma diagnostics software structure. In the figure, circles may represent a task, a sub-group of tasks, or a single task which is instantiated for each diagnostic instrument.

In the sequel, tasks in Figure 3 will be mentioned in parentheses where appropriate to the functions being described.

<u>Controlling a Diagnostic Instrument</u>

Returning to the complete data acquisition problem of Figure 1, the control process uses operator inputs and a control information database (which characterizes the hardware) to effect hardware changes and to produce three data sets. These are, according to the figure, a list of data to be acquired by recorders, current setpoints and latest known hardware status. Much of this data produced during instrument control is required to do sensible data processing. The control process is table driven and produces setpoint and status information in standardized tables as a byproduct of control operations. During the data processing phase of data acquisition, requisite control-produced data is extracted from these tables and made available to data processing codes.

Figure 1 shows only the data flows implicit in the complete data acquisition problem, not when they occur. We model the sequencing of these data flows with three simple control states. In manual control, instrument hardware is controlled directly by operators sitting at workstations. The output data sets are continuously updated but are not used by either the dormant "acquire" process or the dormant "data processing" process. Under local shot cycle control, manual control is locked out, and the single diagnostic instrument proceeds through a locally coordinated (by "Coordinate Shot Sequences") automatic control, data acquisition, and data processing sequence. A snapshot of control-produced data is passed to the two following processes as part of this cycle. Under global shot cycle control (from "Physics Shot Synchronization"), one or more diagnostic instruments are locked in time sequence to a global timing system and thus to sequenced operation of MFTF-B plasma heating systems. The sequence for each involved diagnostic is otherwise no different that it would be for local shot cycle control.

The best illustration of how instrument control actually works at MFTF-B is to follow through two scenarios. The first is how an operator setpoint change reaches hardware, the second being how a hardware status change is reported back to an operator.

To an operator sitting at a plasma diagnostics workstation, the diagnostic instrument control interface appears very much like a commercial spreadsheet. Details have been presented elsewhere[9]. From the operator's point of view, the operator makes an entry into a spreadsheet cell, the spreadsheet may apparently do some recalculation of one or more cell values in response to the input, and a new, updated spreadsheet is presented. What actually happens is shown in Figure 4.

When an operator makes a change to a cell in a workstation, the workstation task ("Control Table Worksheet"), after some access permission checks, sends an update request to the Diagnostics Data Processor ("Control Diagnostic Equipment") and marks the visible cell with a pending mark. The DDP does more checks and makes a cell entry into its master copy of the spreadsheet, also updating the database copy periodically. As in some commercial spreadsheets, there may be functions attached to a cell; at MFTF-B cell functions are fragments of a small interpreted language called "Metaplex". The DDP executes attached cell functions, if any. Like commercial spreadsheets, these cell functions may result in updates to one or more other cells. These updates are typically arithmetic or common mathematical functions of current cell contents, but unlike commercial spreadsheets, updates may be executed conditionally. Diverging even more from the usual spreadsheet practice, MFTF-B cell functions include generation of commands to the Local Control Computer ("PLEX") in charge of diagnostic hardware. These hardware commands may have arguments which are arithmetic and mathematical combinations of current cell values. The results of cell updates are reported back to "interested" (i.e., displaying spreadsheets) workstations.

The foregoing scenario describes a "simple" operator initiated change to diagnostic hardware. How does the operator see delayed changes in hardware status which may result from a previous control action? Hardware status changes or condition changes reach the operator through asynchronous status reports, or "monitors". The spreadsheet presentation of this is simple; there is a slight blink in the display and one or more cell values change. What actually happens is shown in Figure 5.

PLEX, the software running the Local Control Computer, senses a "significant" (see Ref. 7) change in hardware condition during polling and reports this to the DDP as a "monitor report", an asynchronous message identifying the device changed and its new value. The DDP ("Control Diagnostic Equipment") executes a cell update exactly as in the first scenario, the only difference being that the source of the update request is the LCC rather than a workstation acting on behalf of an operator. As in the previous scenario, new cell values are reported back to "interested" workstations ("Control Table Worksheet"), which update their displays.

Data Acquisition: Shot Cycles

As mentioned, the point at which an operator decides to acquire data marks a transition from manual control to sequenced control, during which data flows from the control process downward in Figure 1. The operator requests either to [illegible]e a part of a globally-coordinated shot cycle [illegible] to have a locally-coordinated shot cycle executed on his behalf. In both cases the shot cycle is modelled as five time milestones with an additional sixth milestone inserted for local trigger generation. The cyclic model is shown in Figure 6.

Since the difference between the two cycles is trivial, I shall refer only to a "shot cycle". The purpose of a shot cycle is to coordinate the operations of MFTF-B plasma generation, plasma heating, diagnostic instrument control, diagnostic data recording, database preparation and data archival so as to arrive at a uniquely named, well-defined, self-consistent package of data and initial results that describe an experimental shot. Plasma generation and plasma heating are not subjects of this paper; they will be presumed to occur in appropriate sequence with the diagnostic operations to be described.

For diagnostic instruments, a shot cycle begins at S1 (see Figure 6) at which point the controlling tasks for all involved diagnostic instruments are queried (by intertask message) "is it safe to proceed?". Each control task ("Control Diagnostic Equipment") makes a determination based upon the current known state of its instrument(s) and the type of experimental operation intended (e.g., shot with plasma). A negative reply to S1 aborts the shot cycle.

At S2, presuming that no instruments have protested, the shot cycle coordinating task ("Coordinate Shot Sequences") creates a database archive unit (Figure 7) for data storage and notifies the subset of installed instruments which will actually participate in the experiment. Uninvolved diagnostic control tasks have been warned to avoid control operations which would place their instruments at hazard. Involved control tasks begin instrument preparation by executing an "instrument preparation" spreadsheet function. Operator inputs are locked out, but LCC monitor updates are not, allowing sequenced feedback control instrument conditioning. When instrument preparation is successfully completed, each participating diagnostic control task creates subdirectories in the shot archive unit, stores snapshot copies of its data acquisition list and its control tables (spreadsheets), rewrites the data acquisition list to its Local Control Computer if the list has changed, and creates and initializes raw data storage tables in the archive unit. Each participating diagnostic task then reports back success or failure.

At S3, the shot cycle coordinator notifies the data processing management task of which diagnostics will participate and of the name of the archive unit being used for data. The data processing manager task ("Process Data") creates subdirectories for results storage and begins loading "processing templates" in processing queues.

At S4, there are 10 seconds remaining until hardware trigger. S4 is the last chance diagnostic control tasks have to halt the shot. Each diagnostic control task instructs its Local Control Computer to arm the diagnostic timing system and to set the name of the data storage archive unit into an LCC variable. If the sequence is a locally coordinated shot cycle, S4 is followed after 10 seconds by an S4.5, which directs the receiving diagnostic task to perform its own hardware trigger.

At hardware trigger, data recorders begin recording data. The LCC ("PLEX") polls recorders to determine when they are done. As recorders complete data acquisition, the LCC prepends the archive unit name, a data name, data location information and status information to packets of data, which it then sends to the Diagnostic Data

Processor. Because of the prepended identification, the DDP ("Receive and Store Raw Data") targets received data directly to the database location prepared for it.

At S5, the experimental shot is declared over. Each diagnostic control task starts an acquisition cleanup timer, which is used to purge hung data and to clear the system for the next shot cycle. Timers are also started in the archiving task and the data processing management task so that data archival and data processing can be forced to completion after reasonable intervals.

Processing Acquired Data

The effect of a shot cycle is to bring together in one archival module all of the recorded data, control setpoints, configuration data and hardware status required to produce useful processed results. A data processing manager task ("Process Data") running in the Diagnostic Data Processor uses a "processing template" to load data processing programs in dependency order and to connect the correct input files and output files to them. A template describes the dependencies between processing jobs, describes input data needed by the jobs, and assigns names to results which are produced.

Details of data processing management at MFTF-B can be found in[11]. A template load produces a multiply-linked list of queues of jobs and a list of named results expected to be produced. Jobs are promoted through queues based upon priority and upon the availability of data they require for inputs. There is a ready queue and an abstract batch machine which accepts ready jobs for execution. Both the templates and the results produced are stored back into the shot archive unit, thus completing a packaged description of an experiment.

Seeing Results

We close the data flow loop by making graphical results available to the experimentalist, who then makes decisions to adjust set points either in diagnostic equipment or in MFTF-B operational parameters. A results list is obtained by the diagnostic operator by requesting the same in a workstation results window ("Results Worksheet"). The workstation task obtains a results list from the DDP ("Do Displays") and results may then be requested by name from the list. The names used are those assigned by the processing template.

A results request causes a results window to appear on the workstation screen, in which the graphical or text result is displayed. More than one such window may be displayed on the screen, and windows may be moved around, stretched or shrunk, hidden or exposed as the operator desires. A screen dump to laser printer capability permits an operator to get an (almost) immediate copy of exactly what is shown on the screen. A more detailed description may be found in[12].

Actual Operating Experience

The Magnetic Field Alignment diagnostic instrument[13] was operated using this system during MFTF-B commissioning tests ("PACE test") in February, 1986. As an overall evaluation, we had some problems with system software, but we were prepared and able to take data and to do calculations, albeit less elegantly than we had planned. In general, our problems fell into three areas: speed, network bugs, and mis-sequencing of MFA hardware.

The system would have been more satisfying to use had it been quicker. In the DDP, graphics calculations took time, but were almost as fast as the MFA mechanical hardware could produce data. More serious was the time required by the graphics workstations to rearrange displays and to respond to user menu picks. This time could be as much as 30 seconds in the case of calling up a new graphics presentation. Substantial improvement appears to be possible by increasing workstation local memory to 4 MByte and upgrading to the 68020 processor. A factor of six improvement does not seem unreasonable from Sun Microsystem's published figures.

We had communications bugs between the Sun Workstations and the DDP, mostly because we had time only to implement the UDP/IP DARPA protocols on the DDP (which had no networking software at all). Networking problems will be fixed by upgrading to TCP/IP when staff is available.

We had a significant mis-operation problem with MFA hardware which required that we go to a fallback operation scenario. The problem is correctable and is limited to a single text file which describes MFA spreadsheet cell functions.

While we had problem areas, the rest of the system worked quite well. In particular, our objective of making sure that hardware and control status passed automatically to data processing software worked without a hitch. Users found the interactive spreadsheet control paradigm convenient and easy to use. About a half-hour of training followed by a day or so of practice getting used to the mouse produced reasonably competent operators. Physics staff liked the ability to manipulate graphs, to place them in some preferred arrangement, and then to do a screen dump.

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Figure 1: Data flow model of the complete data acquisition problem at MFTF-B.

Figure 2: That portion of SCDS hardware which is used for diagnostic instrument control, data acquisition, and data processing.

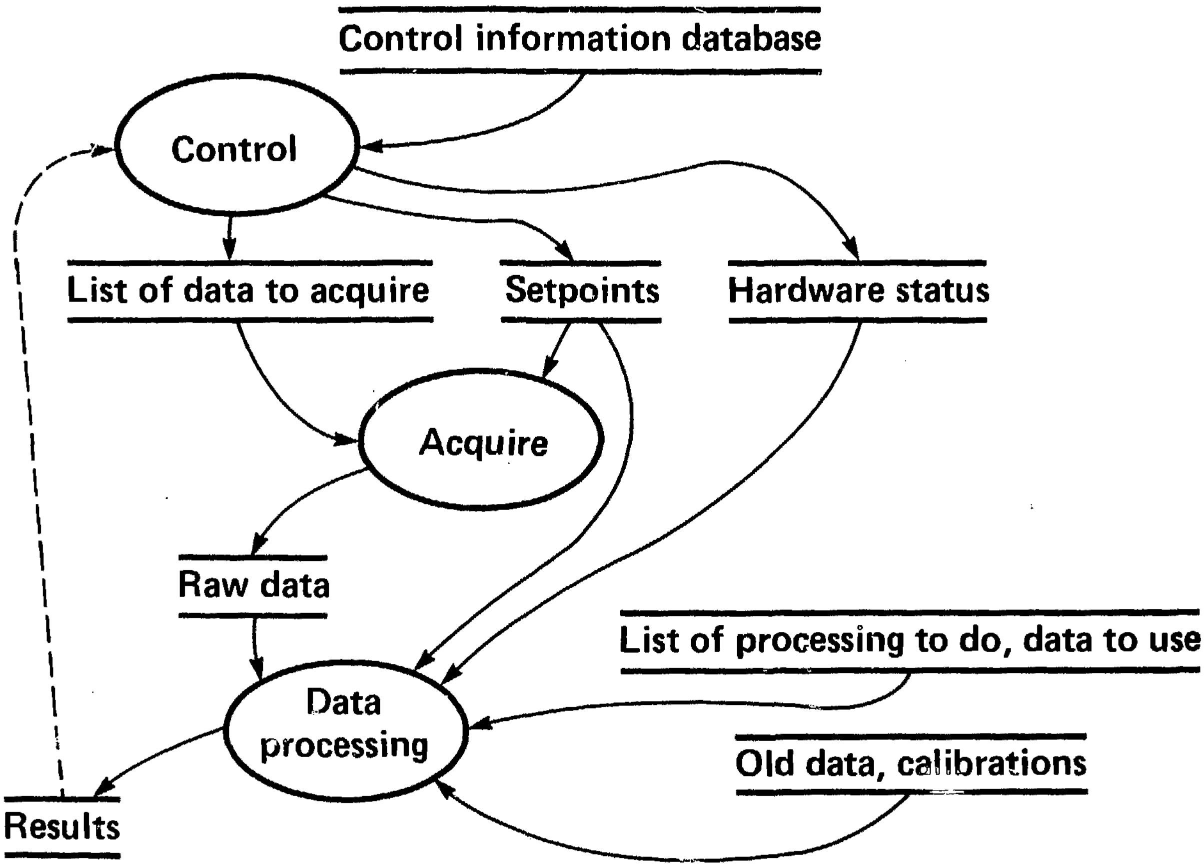
Figure 3: Data flow model of the structure of MFTF-B plasma diagnostics software.

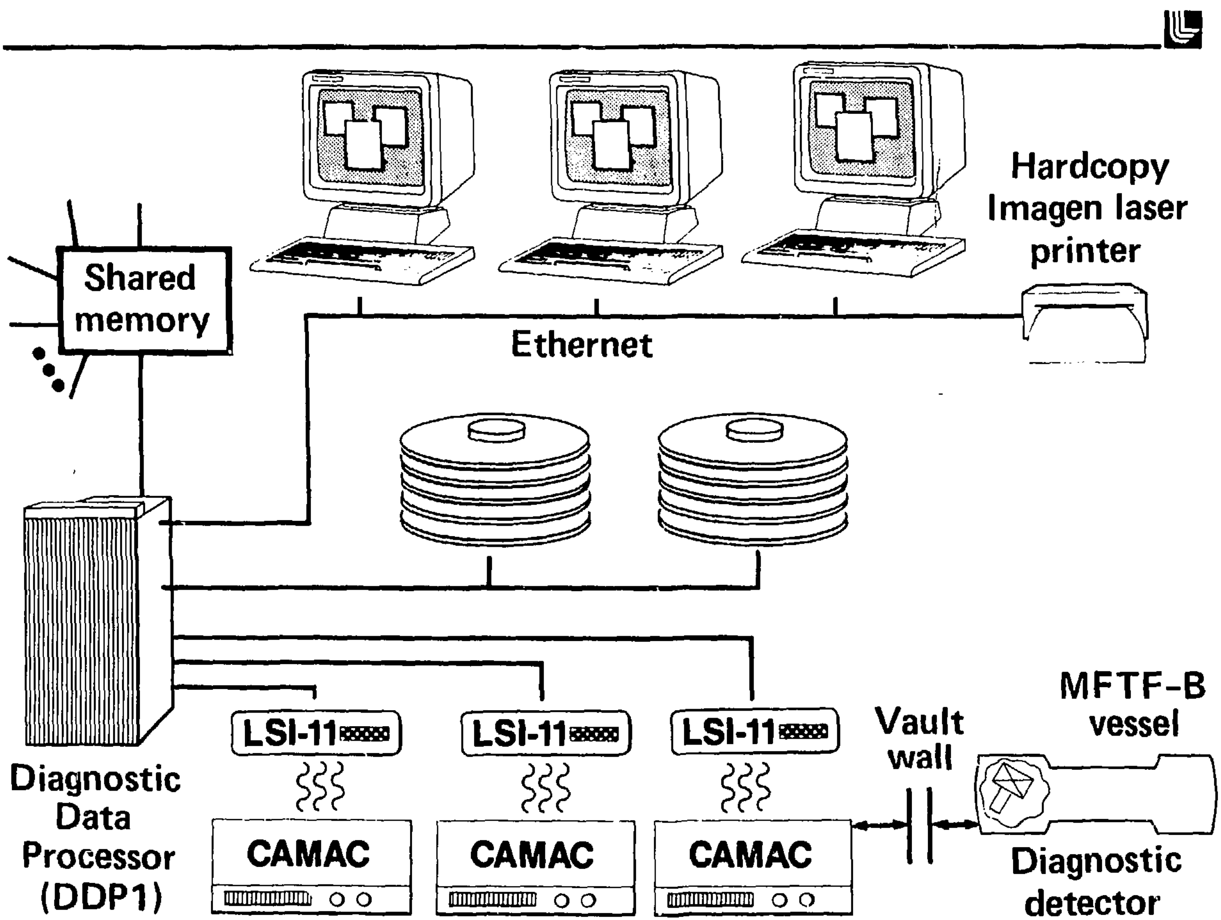
Figure 4: An operator-initiated manual control action.

Figure 5: An asynchronous hardware status update occurring by "monitor" report from PLEX.

Figure 6: Model of the MFTF-B shot cycle, modified for plasma diagnostic instruments.

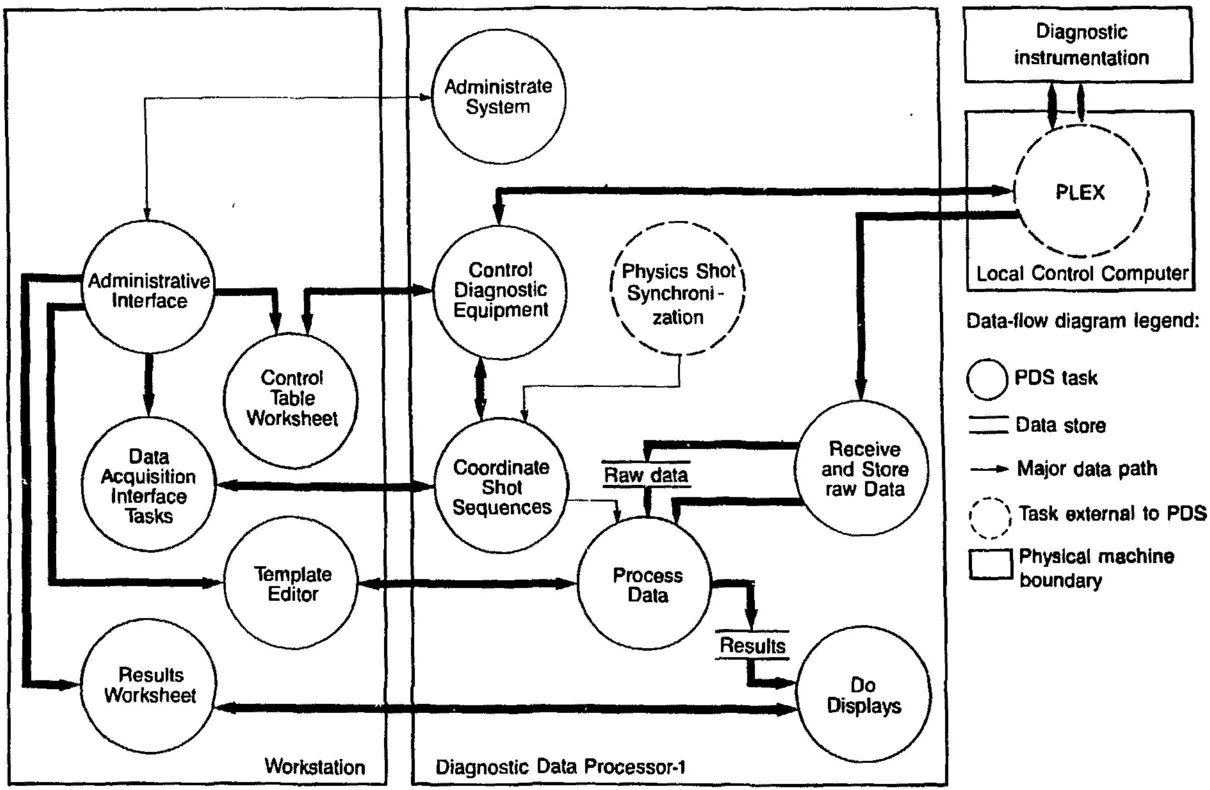
Figure 7: An archive is similar to a disk volume in that it has an hierarchical internal directory structure which catalogs objects. The objects are database[10] tables or files. At MFTF-B, the internal directory structure is standardized, as are several table formats. Archive units are intended to be written to (or recovered from) tape or other storage media as single entities.


Control information database
Control
List of data to acquire
Setpoints
Hardware status
Acquire
Raw data
List of processing to do, data to use
Data processing
Old data, calibrations
Results

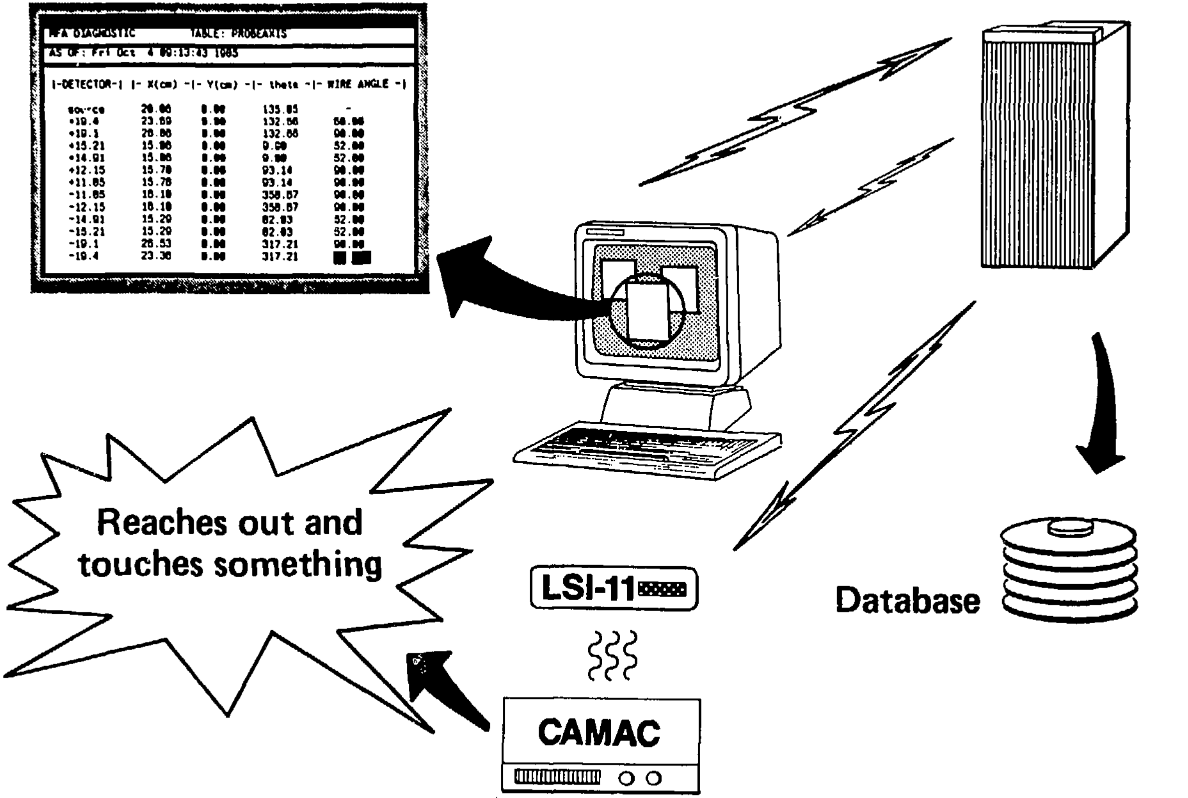


Shared memory
Ethernet
Hardcopy Imagen laser printer
Diagnostic Data Processor (DDP1)
LSI-11
LSI-11
LSI-11
CAMAC
CAMAC
CAMAC
Vault wall
MFTF-B vessel
Diagnostic detector

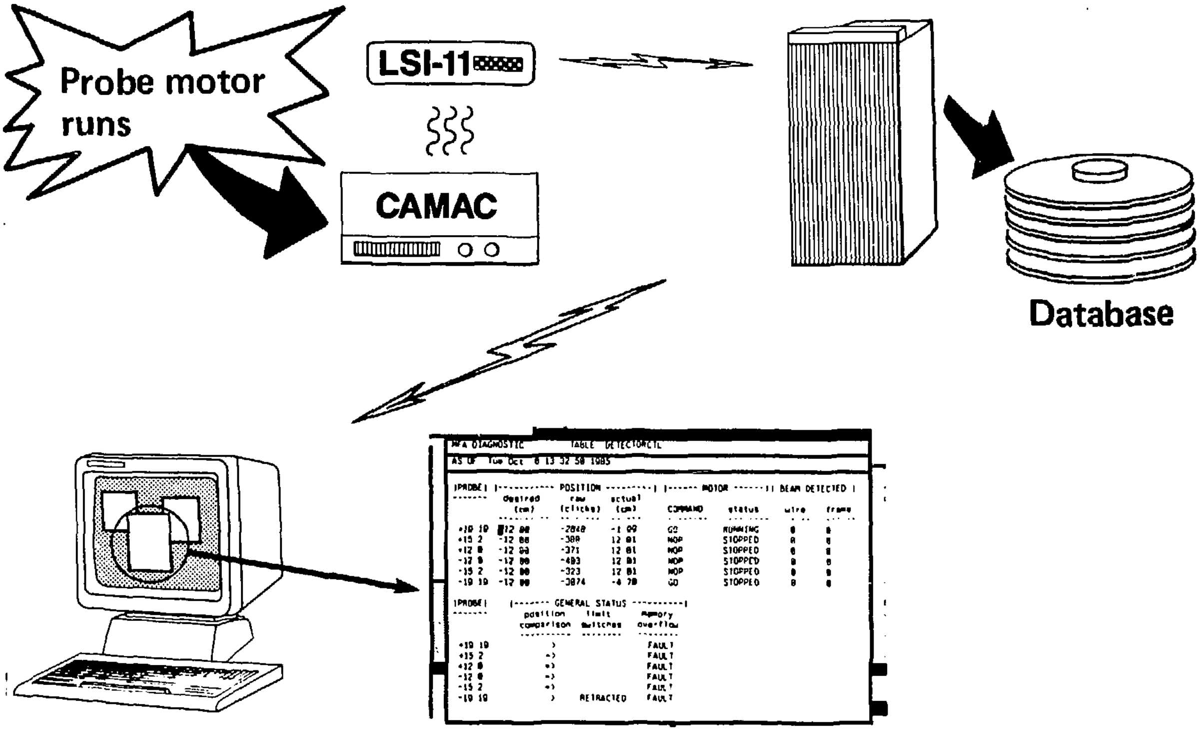
MFTF-B Diagnostics software structure

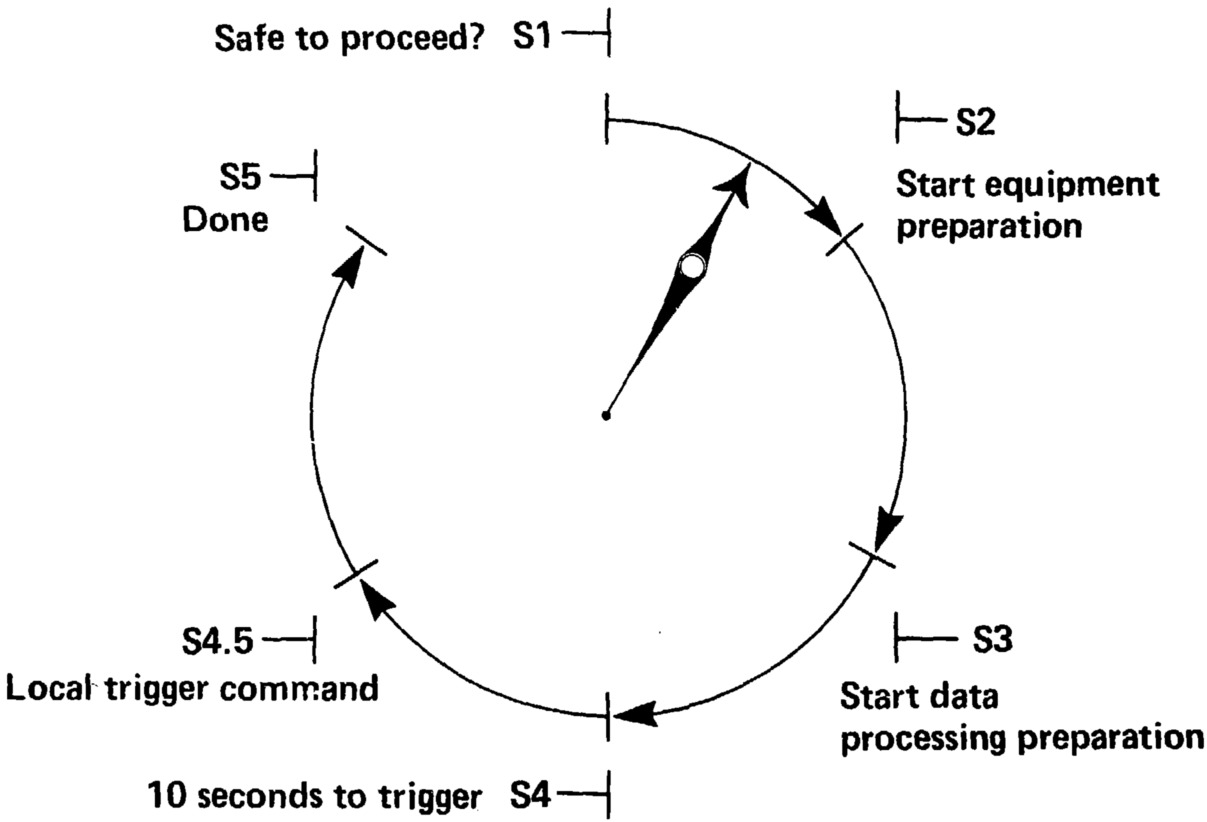


Control


DIAGNOSTIC TABLE: PROBEAXIS
AS OF: Fri Oct 4 09:13:43 1985
|-DETECTOR-| |- X(cm) -|- Y(cm) -|- theta -|- WIRE ANGLE -|
source 20.00 0.00 135.85 -
+19.4 23.89 0.00 132.86 60.00
+19.1 20.86 0.00 132.86 90.00
+15.21 15.86 0.00 0.00 52.00
+14.91 15.86 0.00 0.00 52.00
+12.15 15.70 0.00 93.14 90.00
+11.85 15.78 0.00 93.14 90.00
-11.85 18.10 0.00 358.87 90.00
-12.15 18.10 0.00 358.87 90.00
-14.91 15.20 0.00 82.83 52.00
-15.21 15.20 0.00 82.83 52.00
-19.1 28.53 0.00 317.21 90.00
-19.4 23.30 0.00 317.21
Reaches out and touches something
LSI-11
CAMAC
Database

Control




Safe to proceed? S1
S2
Start equipment preparation
S3
Start data processing preparation
10 seconds to trigger S4
S4.5
Local trigger command
S5
Done

Data Acquisition

Universal archive unit structure