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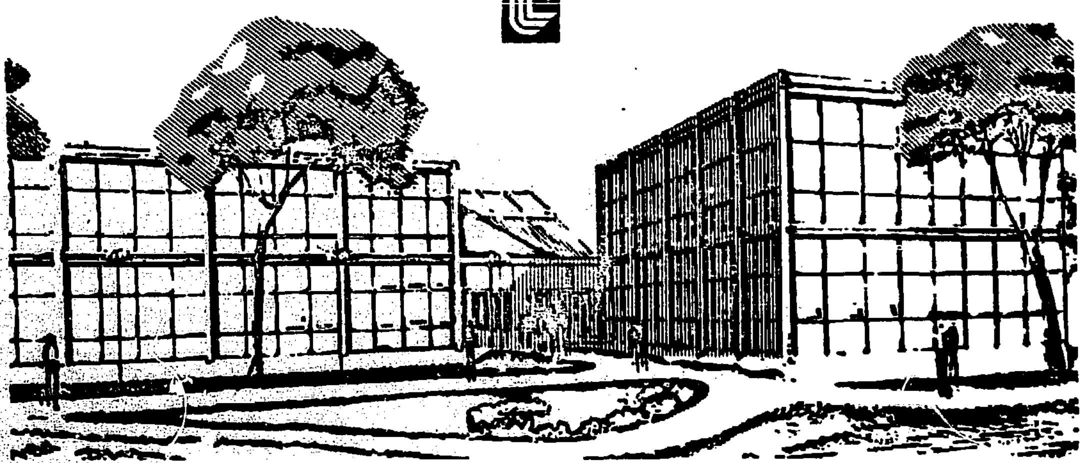

HIERARCHICALLY STRUCTURED DISTRIBUTED MICROPROCESSOR NETWORK FOR CONTROL*

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Introduction

Shiva is one of a series of increasingly higher power glass laser facilities developed at Lawrence Livermore Laboratory in a program with the ultimate goal of generation of power from a controlled fusion reaction. Shiva is a 20-arm neodymium-doped glass laser system with an output of 30 terawatts of 1.06 micron light. The laser became operational in November 1977 with the first target irradiation experiment in May 1978, and is now fully operational.

To satisfy a broad range of control-analysis and data-acquisition requirements for Shiva, we have designed and implemented a hierarchical, computer-based, modular-distributed control system. This system handles the more than 3000 control elements and 1000 data acquisition units in a severe high-voltage, high-current environment. The control system design gave us a flexible and reliable configuration to meet the development milestones for Shiva within critical time limits.

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<u>System Architecture</u>

By competitive bid, Shiva has standardized its control system around Digital Equipment Corporation's PDP-11 minicomputer and LSI-11 microprocessors. This single family of upward instruction-set compatible machines is used in all levels of the hierarchical system for control, analysis, and data acquisition. The control system uses 50 LSI-11's, four PDP-11/34's, and a PDP-11/70 to perform the necessary system functions, as shown in Figure 1.

The LSI-11's serve as general purpose, front-end processors (FEP) and are distributed throughout the laser and target bays, as well as in the control room. These FEP's provide local control, data collection, data compaction, feedback control, system monitoring, and direct operator interaction functions. The FEP's are connected either directly to one of four PDP-11/34's, or indirectly to a PDP-11/34 through concentrator FEP's.

The PDP-11/34's serve as subsystem controllers performing man-machine interaction through color displays, plasma panels with touch control, and special-purpose control panels. Additionally, these medium-level PDP-11/34's provide for overall coordination and utility of a particular subsystem. The four distinct areas of subsystem responsibilities from a laser viewpoint are:

- Alignment.
- Power conditioning.
- Laser diagnostics.
- Target diagnostics.

The control system design and implementation reflects these areas with a distinct subsystem PDP-11/34 as the top processor for each area.

The integration and coordination of the subsystems is accomplished by the connection of the PDP-11/70 system with each of the PDP-11/34's. The PDP-11/70 acts as the overall supervisory control for the system, as well as handling the tasks of data archiving, analysis, program development, and PDP-11/34 backup. In addition, all the large peripheral equipment, such as large disks or magnetic tapes, are centralized on the PDP-11/70 with access through an intercomputer network from each of the PDP-11/34 subsystems.

Development and Implementation

We were able to successfully implement the Shiva control system on a very tight schedule because of parallel development on parallel processors and the standardization around a family of instruction-set compatible machines.

The designation of four subsystems and the subsequent creation of subfunctions within each area allowed the definition and development of each subfunctional area on a separate microprocessor (FEP) that was somewhat independent of other subfunctions. This parallel development allowed individual subfunctions to become operational when necessary, without having to wait for other subfunctions.

The standardization on LSI-11 FEP's allowed the transport of hardware and software between FEP's whenever appropriate. Also, system-level support, such as operating-system and language changes, could be provided by a small number of people for all the FEP's.

The standardization around a family of instruction-set compatible machines at all levels allowed the software support and development to be done on the PDP-11/70 for the PDP-11/34's and LSI-11 processors. It also allowed the same programs that were initially run on FEP's to be transported to the PDP-11/34 processors and run. The laser system, for instance, was originally brought up with only FEP control.

Integration and coordination of the parallel development effort was accomplished by planning, designing, and implementing the system as a single, distributed control and data acquisition system. We strove for commonality of design concepts, hardware and software wherever possible.

Intersystem Communication

Communication between processors is accomplished through three distinct hardware and software interconnections:

- Parallel communications link (PCL) - DECNET.
- Serial asynchronous links - SHIVANET.
- Common memory - task to task.

The interconnection of the PDP-11/70 and PDP-11/34's is accomplished with the PCL, a high-speed (500K word/s) parallel path. The generalized networking software, DECNET, is used over this link to allow file transfer and task synchronization between machines. DECNET provides generalized high-level functionality between processors but is considered too slow for direct-control operations.

Most front-end processors are interconnected through fiber optic serial asynchronous links. A typical data rate between FEP's or FEP to PDP-11/34 is 9600 baud over these serial links. SHIVANET, a special control-system-network software package, was implemented to allow control-system commands to be sent between systems with minimum software overhead in both time and space (memory). The SHIVANET software is a straight-forward protocol allowing transfers of small packets of control information between the machines at essentially hardware speeds.

The third interconnection mechanism between processors is common (or shared) memory in the power conditioning subsystem. This is a quad-ported memory shared by the PDP-11/70, PDP-11/34, and two redundant LSI-11's. Machine-to-machine communication is handled through data and control areas in this memory with the appropriate handshake flags. Data from the FEP is archived on the PDP-11/70 disk through dedicated programs in each machine communicating through the memory.

Each of the above intersystem communication methods has some advantages and some disadvantages. The combination gives a viable solution to the communication problem in the Shiva control system.

A Typical Shiva Control Subsystem

Although each subfunction control within Shiva is different, the general approach is common. Here, we describe an idealized subsystem and how it works.

Figure 2 shows a typical multiple FEP control subfunction. The laser component (a mirror) to be moved is connected to a stepper motor that is interfaced to a particular FEP. This FEP has a local switch panel. An operator can depress a switch and move the selected component. Although this appears simple, it is a complex internal operation. The operation is integrated into a remotely controlled system with possibilities for closed-loop control at any level.

Thus, when the switch is depressed, a polling program in the local FEP detects the change in value of a data bit. This fact is recorded in a common control data area within the local FEP. Another program within the FEP knows that a change in that data area means that a particular motor should be moved. This program sends the appropriate control values to the designated motor interface card, which causes the motor to step and the component to move (i.e., push the button; move the mirror).

Now if we include another program in the FEP to communicate with a second higher level FEP, a message can be received that tells the program to change the same common control data area, causing the same motor to step and the component to move.

If we have a group control panel on the second FEP (see Figure 2), we can first set a value saying which motor (in which FEP) and then depress the step switch. A program in this group FEP reads these values and places them in its own group common data area. Another program in the group FEP decides that those values refer to components connected to another FEP and formats the values into a message and sends the message to the appropriate local FEP. When that FEP gets the message, the component moves as described. Thus, an operator can depress a switch either on the local or group FEP and move the same laser component.

Nesting the above procedures from FEP to FEP, FEP to PDP-11/34, PDP-11/34 to PDP-11/70, allows the particular component to be moved by any machine in the network or by any person communicating to a machine in the network.

All control and data acquisition activities are accomplished with programs on multiple processors communicating by data messages. At some point the control messages arrive at an FEP where they are converted to physical operations (motions). Data acquisition occurs through the FEP's reading a value from an interface, converting it into a message, and sending it up through the network to the proper destination.

Concepts

The important concepts common throughout the Shiva system that allow local and remote control by operators, as well as automatic control by the system, are:

- All components interfaced to FEP's.
- Multiple processors.
- Multiple processes within processors.
- Common data areas for communication and control in each processor.
- Communication between processors.
- Man-machine communications through switch panels, color displays, and plasma displays with touch control.

Note that the details on how each of these six concepts are implemented are unimportant to accomplish the automatic and manual control functions. The details, however, do influence the cost, performance, and schedule of the control system. On Shiva, each subsystem uses some unique software and hardware designs as well as some common software and hardware to supply the six needed control system requirements listed above.

Man-Machine Communication

Control of laser and target systems is accomplished through preprogrammed sequences and manual operation. Manual operation consists of an operator communicating with system programs to directly perform an operation or to change a preprogrammed sequence. This communication between operator and system is accomplished through:

- "Soft-wired" switch and status panels.
- Computer terminals.
- Color displays.
- Plasma display panels with touch control.
- Programmable switches.

In many cases, a human operator interacts with a combination of these devices. Overall control for the laser system is provided by a central control console. Initial Shiva laser and target shots in 1977 and 1978 used both local and central control consoles. Total integration of the control and data acquisition functions has required completion of the central control console and integration of all the subsystems. This has allowed routine day-to-day operation of Shiva as a research facility.

Major Computer Hardware System Summary

PDP-11/70

Memory:	384K 16-bit words (core).
Storage:	RP-06 drive (176M bytes).
	4 RK-05 cartridge drives (1.2M bytes each).
	1 RX-01 floppy disk (2 drives).

Displays: 1 VSV-01 color display.

Tektronix 4014 graphic terminal.

Orion plasma panel.

Terminals: 10 HP-2645 editing.

Printers: 2 Versatec D-1110A printer/plotters.

PDP-11/34 (four)

Memory: 128K 16-bit words (core).

Storage: 3 RK-05 drives.

Displays: 1-4 VSV-01 color displays.

1-2 Orion plasma panels.

Terminals: Console DECwriter II.

LSI-11 (50) - Many as ROM based slave processors

Memory: 28K 16-bit words (ram), or

4K core and 5K ROM

Storage: Some with RX-01 floppy disks

Displays: Some with HP-2645 video displays

Terminals: Some with DECwriter II or TI 763 terminals.

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SHIVA CONTROL SYSTEM

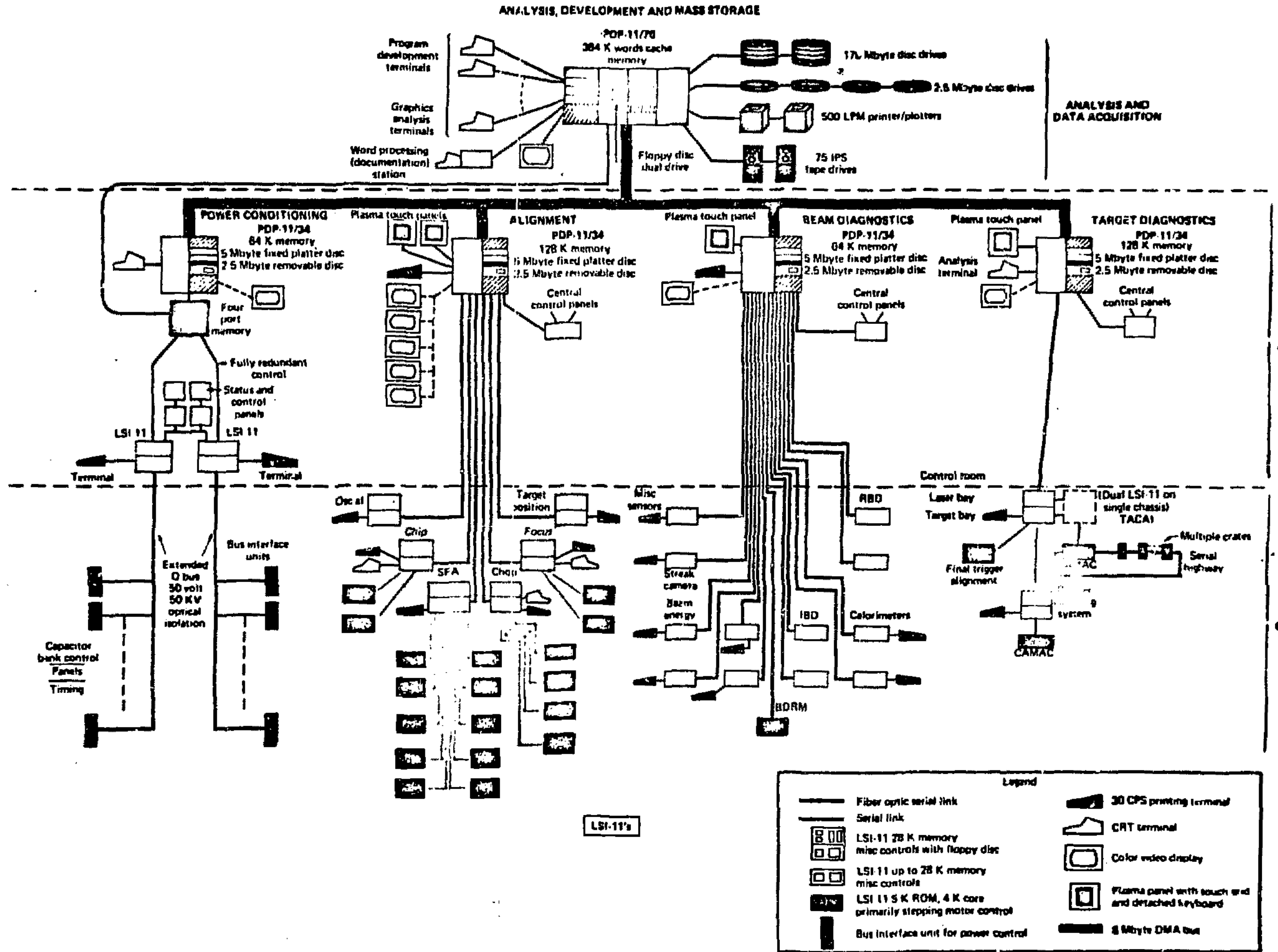

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Figure 1

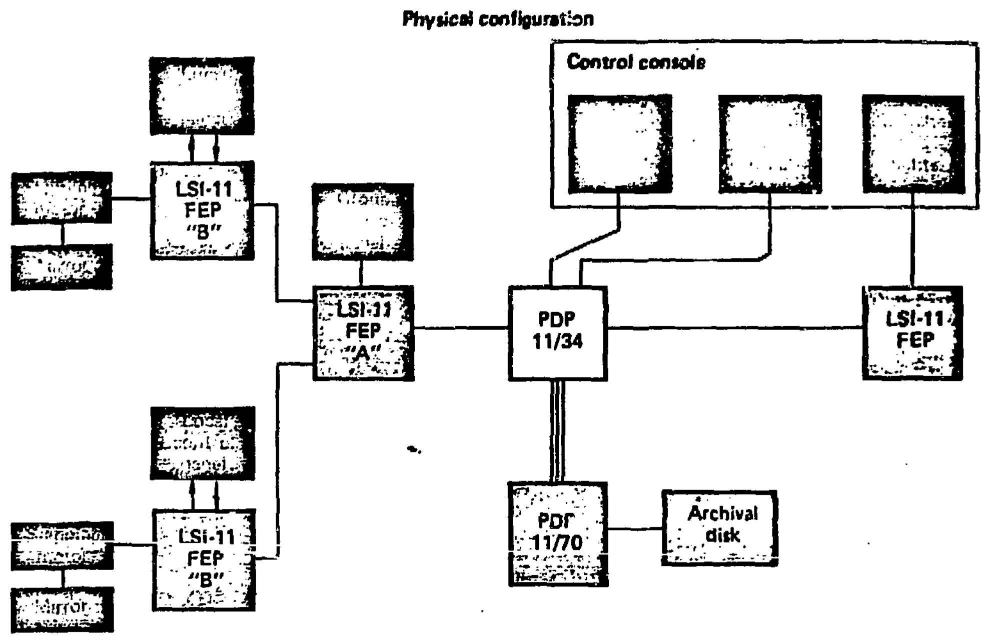

Fig. 2 A typical control subsystem with logical connections between the central control console, through the processors, to the optical components. Control operations are performed by sending messages between the processors.