DANIEL P. PELETIER

THE APPLICATION OF A DISTRIBUTED COMPUTER ORGANIZATION TO OCEAN RESEARCH

The computer is an essential tool for experimenters, analysts, and scientists, both in the field and in the laboratory. A coordinated approach to the use of computer resources and associated personnel can significantly improve an organization's ability for quick acquisition, analysis, and dissemination of scientific data. Such an approach is described in this article and is illustrated by its use in an at-sea hydrodynamic experiment.

INTRODUCTION

The APL Submarine Technology Department investigates the physics of the ocean and the atmosphere-ocean interaction. A vital part of the Department's research effort involves experimentation with at-sea projects concerning multiple platforms and lasting for more than a week, conducted several times each year. Such experiments generate enormous quantities of data, the successful acquisition and processing of which require a smoothly functioning, distributed computer organization.

The programs conducted by this Department spend more than $1 million annually for computer hardware, software, and personnel to support data acquisition and evaluation at sea and data analysis at APL. The ability to reuse hardware and software, to reassign personnel easily, and to size resources to fit the experiment without redesigning the system is essential to the Department's efficiency. At the same time, considerable flexibility—critical to successful creative research and development—must be maintained. In this article, the Data Acquisition, Processing, and Analysis Center that coordinates the computer resources of the Submarine Technology Department is described, and the application of computer hardware, software, and personnel resources to a major at-sea experiment is illustrated.

DESCRIPTION OF THE COMPUTER ORGANIZATION

Three features in particular are the keys to the success of the computer organization:

1. An information-processing group provides the computer hardware, software, and personnel to support the technical specialty groups that sponsor the at-sea tests and the subsequent data analyses. The technical specialty groups within the Department naturally tend to propose computer systems that are closely tailored to their specific application, while the Department naturally tends to purchase computer systems that take advantage of the cost effectiveness of commonality. To ensure that both tendencies are properly balanced, an information-processing group negotiates with peer technical specialty groups to recommend computer systems for program and Department approval.
2. A representative of the information-processing group serves on the experiment team to ensure that the computer services necessary for the experiment are available and that the Department perspective on computer resources is represented.
3. A steering group consisting of representatives from each Departmental group cooperatively plans for future computer resource needs. Plans, of course, must be approved both by the Department and the sponsoring agencies.

The organization employs a set of coordinated computer resources (hardware, software, and personnel) encompassing portable data acquisition suites, workstations dedicated to individual technical group needs, and a data processing center that supports at-sea computer operations as well as in-house data processing, management, analysis, and dissemination. Efforts are coordinated through the Data Acquisition, Processing, and Analysis Center, which is based on the computer systems shown in Fig. 1. The PDP-11/34-based data acquisition systems and the PDP-11/55-based workstations use the RSX-11M multiuser operating system. The VAX-based data processing center uses the VMS operating system, which executes a recompiled source code generated under RSX-11M, as well as a code generated under VMS. Thus, the workstations are used to generate a code that runs not only on the workstations but also on the portable data acquisition computers and the central processors.

A network interconnection provides remote access to the central Department processors from special-purpose workstations such as the vessel track reconstruction processor and the image processor. The image processing workstation, for example, sends picture frames to the FPS-164 attached processor via the net-

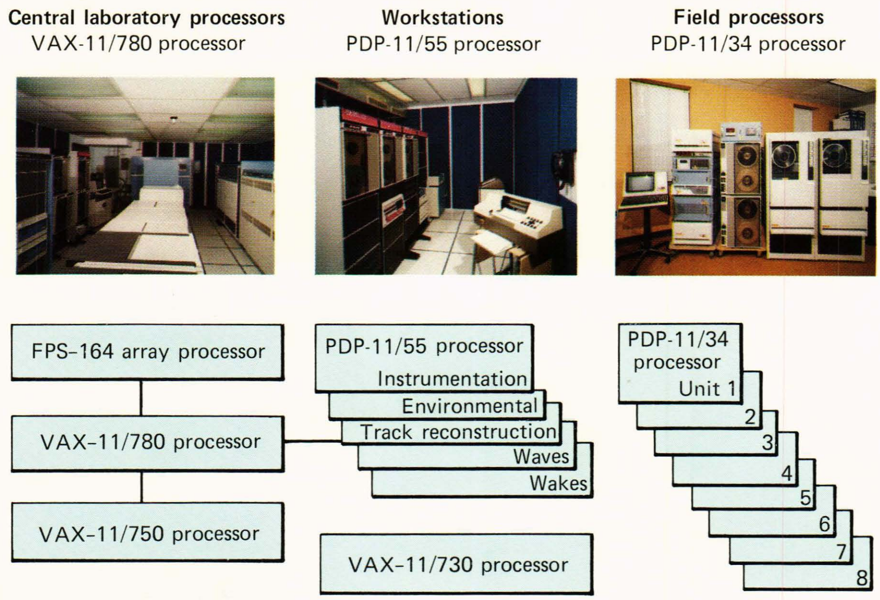

Figure 1—The Data Acquisition, Processing, and Analysis Center.

work. After the frames are processed, they are returned via the network and are displayed on the special-purpose graphics equipment of the image processing workstation. Thus, the special-purpose peripherals associated with workstations are matched to the user's needs, yet the network provides access to the central processor as needed.

The continuity provided by common equipment and operating systems allows the gradual evolution and reuse of software even though the initial software is developed for a particular need and is inevitably written on a rush basis. Data acquisition software, quick-look analysis software, and instrument-verification software are modularized to allow special-purpose procedures to be added easily. Professional software development personnel, who work with common software and hardware, revise the software to make it flexible and general purpose. The information-processing group ensures that software is documented well enough to be easily reused and maintained.

Flexibility at the sensor/data acquisition computer interface is maintained by using embedded computers in the highly intelligent sensor suites. Compatibility is maintained by controlling the interface to the data acquisition computer aboard ship. The information processing group representative on the test team ensures that the computer, associated software, and related personnel perform their roles properly.

The value of this distributed computer organization concept is illustrated by a recent at-sea experiment that employed multiple microprocessor-based sensors, multiple data acquisition and quick-look analysis computer systems, and multiple data processing and signal processing computers.

The experiment measured vertical and horizontal temperature variations by means of a vertical array of temperature sensors towed behind a research vessel (see Fig. 2). As the array was towed through the water, it measured temperatures at depths along the array. Internal waves may cause an entire water mass to move up and down, and that motion results in temperature sensor readings that deviate from the expected temperature gradient and thus reveal the motion of the water mass. This motion of internal waves is the physical phenomenon of interest.

The temperature variations are small (measured in thousandths of degrees), and the sensors must be calibrated to remove errors caused by sensor nonlinearities. Each sensor has its own set of calibration constants that are applied to the data in real time. Sensor and electronics operation is also validated in real time. To support calibration, test, and data acquisition tasks and to control transmission of data back to the onboard data acquisition computer, a microprocessor is built into several fairings to control 20 thermistors (see Fig. 2). A microprocessor-based interface unit on the tow ship unscrambles the data from the sensor microprocessors and translates the information into the proper format for the on-board PDP-11-based data acquisition computer.

Besides showing the effects of internal waves, the water temperature varies over the short term because of such phenomena as water mixing by the interaction of wind and storms, the motion of currents and schools of fish, and so forth. As a result, the temperature data alone do not present a clear picture of internal wave motion. Models of internal wave motion that take the interfering phenomena into account have been developed, and a great deal of processing is done to remove such effects and to allow the experimenter to observe better the internal wave motion. This data processing is done at APL on the VAX-11/780 and FPS-164 attached processor or on the PDP-11/55 workstations.

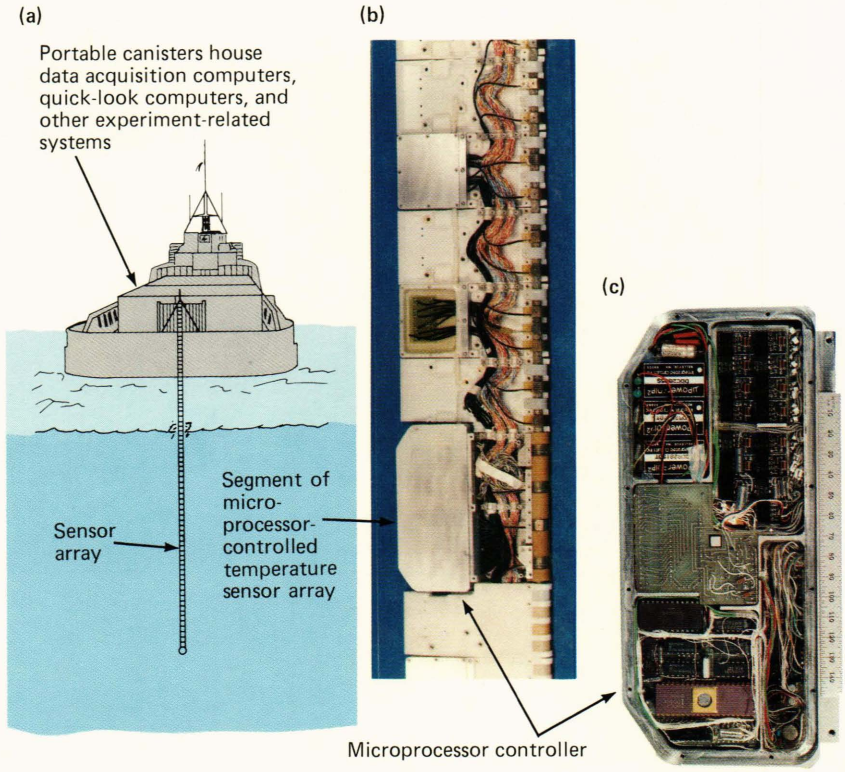

Figure 2—Distributed computer-based temperature measurement and analysis system. (b) is a segment of the microprocessor-controlled array shown in (a). (c) is an enlarged view of the microprocessor controller without the cover plate.

DATA ACQUISITION, CONVERSION, AND VALIDATION

The PDP-11/34 data acquisition computers and associated software represent the boundary between the raw data and the processing software. The temperature array data mentioned above are digital, but auxiliary information such as ship's speed and heading is analog. Thus, the data acquisition system must accept both analog and digital data and handle digital data in varying formats. To understand the detailed input data formats and translate them into formats that are useful to analysis software is a time-consuming process that can result in analysis delays of months if the proper approach is not used. Moreover, the analyst can deal more easily and quickly with data that are presented in well-defined engineering units. The Data Acquisition Program described below not only presents a simple interface to the analysis software but also validates the data, converts them to engineering units, and displays them in real time. This processing is accomplished while data acquisition rates up to 75 kilobytes per second are maintained. The program uses multiple buffers and controls two tape drives so that reels may be changed on one drive while data are acquired on the other.

The Data Acquisition Program is easily reconfigured. Its flexibility results from the way it separates software modules into three categories and the simple mechanism it uses for control (see Fig. 3). First, generic modules provide such services as buffer management, tape input/output, and error message logging that are needed by all data acquisition configurations. Second, device-dependent modules support such specific instrumentation interfaces as analog-to-digital converters and interfaces to special-purpose instruments like the thermistor array. Third, a configuration-specific module controls the generic and device-dependent modules and formats the data acquisition sequence for a particular application. This control mechanism is a single module that contains a list of subroutines to be executed by an interrupt service routine. The reconfiguration thus reduces to a simple modification of the subroutine list. The device-dependent modules are generally written in PDP assembly language, but the configuration module is written in Fortran. Thus, the Data Acquisition Program adapts readily and quickly to new configurations yet takes advantage of the speed of assembly language device interfaces.

Finally, the consistent structure of the output data from the Data Acquisition Program has resulted in the development of a simple read routine that retrieves the data from tape for use in processing programs. The ease of access to the data not only simplifies and hastens processing at APL but also simplifies and hastens quick-look analysis at sea, generally done on a separate PDP-11 computer.

DATA MANAGEMENT

As part of the test team, personnel from the information-processing group establish data acquisi-

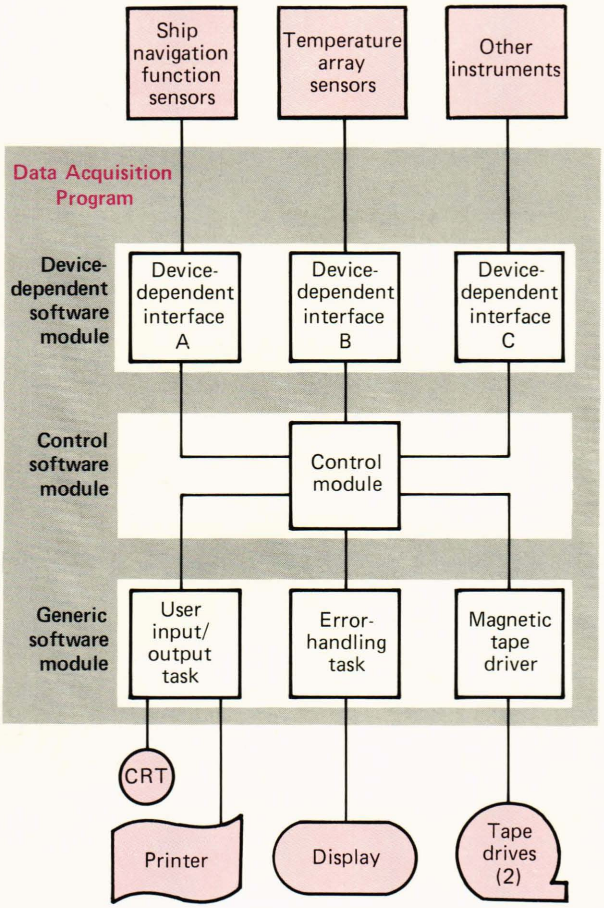

Figure 3—Data Acquisition Program system concept.

tion, analysis, and dissemination requirements. The group also provides equipment, personnel, and software before, during, and after the at-sea exercise. By participating in the experiment, information processing group personnel ensure that the transmission of data from the sensors to the data acquisition computers and eventually into magnetic tape libraries and processing computers at APL is accomplished smoothly and efficiently.

The group maintains a Department magnetic tape library with data, logs, and such associated experiment information as vessel track plots. The catalog of the data tape location and status is kept on a file in the Department's VAX-11/780 computer and maintained by the Department data librarian, who is also a member of the information- processing group. Data from an at-sea exercise are generally available for processing, duplication, and dissemination within two weeks after being received from the experiment.

DATA PROCESSING AND ANALYSIS

The data obtained during an experiment are used as input to programs that model such phenomena as two-dimensional internal hydrodynamic wave propagation, acoustic wave propagation, or magnetic wave propagation. Signal processing techniques (such as digital filtering and Fourier transforms) are frequently used to enhance the signal-to-noise ratio of the data, and image processing may also be used to identify objects of interest. These analysis tasks require a high degree of data processing, which is supported by the individual PDP-11/55 workstations and the VAX-11/780 with its attached FPS-164 processor. The computing capacity of the VAX-11/780 is about one-fifth that of an IBM 3033 mainframe. For signal processing algorithms that employ a large proportion of matrix operations, the FPS processor improves execution speed by at least an order of magnitude over the VAX alone and enables the VAX/FPS combination to outperform some mainframes for particular applications. For nonmatrix intensive processing, the attached processor enables the VAX/FPS combination to approach mainframe capability.

CONCLUSION

The systematic approach to the use of the hardware, software, and personnel of the Submarine Technology Department computer resources has demonstrated the flexibility necessary to support efficiently a number of complex at-sea exercises in a single year. There is, of course, never enough computing power to satisfy a fertile scientific mind. Nevertheless, the Data Acquisition, Processing, and Analysis Center concept has significantly reduced bottlenecks in data acquisition and processing to the extent that analysis of data is frequently not restricted so much by the speed of the computing system as by the analyst's ability to assimilate the data. Thus, it is believed that the Center represents an effective blend of coordination and flexibility.