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Articles

In this Issue

The software development process is being subjected to intense scrutiny and a lot of fine tuning these days. In HP's Corporate Engineering Department, the Software Engineering Laboratory leads companywide efforts in software metrics, tools, productivity, and environments, and has been holding an annual Software Productivity Conference. The papers presented at these conferences are full of creative engineering and good ideas. Taken together, they show that HP's software laboratories are investing an impressive portion of their resources in efforts to improve every aspect of the process of software development, an indication that the importance of software is being recognized as never before.

The original versions of the papers on pages 4 through 36 of this issue were presented at the 1985 HP Software Productivity Conference, and the subject of the article on page 37 was presented in a paper at the 1984 conference. Most of the papers deal with internal design, testing, and measurement tools and methods. On page 4, Marty Cagan of HP Laboratories presents a summary of HP's artificial intelligence workstation research efforts, which have so far produced one product, a Common Lisp development environment for the HP 9000 Series 300 workstation family. This product, along with some experimental software and the hardware to run it all, is being given, in a major HP grants program described on page 7, to several universities to aid their research in artificial intelligence and symbolic programming. The cover photo shows the HP Flight Planner/Flight Simulator, an application developed using HP AI workstation technology. The Flight Planner/Flight Simulator is described on page 13.

On page 43, you'll find a short article about the design of a new plug-in ROM package for the HP-71B Handheld Computer. The package makes it easier to program the HP-71B to control the HP 3421A Data Acquisition/Control Unit for low-cost, battery-powered, portable data acquisition and control applications.

-R.P. Dolan

What's Ahead

Scheduled for March are six articles on the design details of the HP 54100A/D and HP 54110D Digitizing Oscilloscopes. These general-purpose oscilloscopes are especially useful for digitial design and high-speed data communications applications. Also in the issue is an article on a software package designed to teach the fundamentals of digital microwave radio.

The HP Journal encourages technical discussion of the topics presented in recent articles and will publish letters expected to be of interest to our readers. Letters must be brief and are subject to editing. Letters should be addressed to: Editor, Hewlett-Packard Journal, 3000 Hanover Street, Palo Alto, CA 94304, U.S.A.

Module Adds Data Logging Capabilities to the HP-71B Computer

This 64K-byte plug-in ROM offers new BASIC language keywords for control of a battery-powered data acquisition and control unit and nine application programs for data capture, presentation, and transmission to host computers.

by James A. Donnelly

THE COMBINATION OF THE HANDHELD HP-71B Computer[1] and the HP 3421A Data Acquisition/Control Unit[2] provides a low-cost hardware configuration for many engineering or production data acquisition applications (Fig. 1). The computer and instrument are connected via the Hewlett-Packard Interface Loop (HP-IL).[3] To assist the engineer in performing data acquisition tasks, a special plug-in ROM module was developed for the HP-71B Computer. This 64K-byte ROM module, the HP 82479A Data Acquisition Pac, contains a hybrid of BASIC and assembly language programs. Six general sets of capabilities are provided:

- BASIC keywords for instrument control. The keyword INIT3421 finds and initializes the specified HP 3421A on the interface loop. Keywords such as DCVOLTS and RANGE provide convenient instrument control. Additional keywords such as TCOUPLE and RTD provide rapid and accurate assembly language linearizations for thermocouple, thermistor, and resistance-temperature detector (RTD) probes.
- Interactive control of the HP 3421A. A BASIC program and keyboard overlay for the HP-71B create a virtual front panel for the HP 3421A, which has no front-panel controls.
- Nine-trace stripchart output for the HP ThinkJet Printer.[4] A BASIC program configures the system to produce strip charts with optional data storage.
- System monitoring and control. A BASIC program configures the system to monitor functions in a system, perform limit tests and controls, and display the system status on a video interface. An option allows periodic storage of the system status to a data file.
- Long-term data acquisition and control. Two BASIC programs allow sophisticated data logging and control pro-

Fig. 1. *The HP 82479A Data Acquisition Pac for the HP-71B Computer enables the computer to control the HP 3421A Data Acquisition/Control Unit via the Hewlett-Packard Interface Loop, allowing an engineer to configure low-cost, battery-powered systems for data logging or instrument control.*

cedures to be configured and executed without user intervention.
- Data analysis. A BASIC program provides printed analysis of data collected by the stripchart, system monitor, or logging programs. The data can be printed, summary statistics can be calculated, or a strip chart can be generated from stored data. Two additional programs provide data transmission to MS™-DOS-based computers (via HPLink) or to HP 9000 Series 200 and Series 300 Computers.

New BASIC Keywords

The Data Acquisition Pac's capabilities are based on a series of BASIC language keywords that combine conventional instrument control steps into one action. The conventional procedure for reading an instrument in HP BASIC languages has been to use the OUTPUT statement to send a command sequence to the instrument and then use an ENTER statement to receive the data from the instrument. The keywords provided in the HP 82479A ROM combine these operations into one, which provides several benefits:
- Ease of programming: the engineer is no longer required to refer to the instrument manual for cryptic commands. For example, A=DCVOLTS replaces OUTPUT :6;"F1T2"@ ENTER :6;A
- Enhanced code maintainability: an engineer assigned to take over responsibility for a test program using these keywords will experience a shortened learning curve while reviewing the code.
- Speed enhancement: the combined operations reduce operating system overhead for the processing of the OUTPUT and ENTER statements. The keywords TCOUPLE, THMST2, and RTD provide rapid and more accurate conversions from voltage or resistance measurements than equivalent routines written in BASIC.
- Device location independence: unlike the HP-IB (IEEE 488), where the addresses of the instruments must be set manually, the HP-IL assigns device addresses automatically. The keywords in the Data Acquisition Pac complement this by not requiring instrument address information. If more than one HP 3421A is connected to the HP-IL, a consistent device addressing scheme makes selection of the first instrument on the loop the default choice, but permits selection of additional HP 3421As.

The new keywords provided by the ROM do not preclude the use of ENTER and OUTPUT statements to control the HP 3421A, creating a possible conflict between commands issued through the new keywords and commands sent with the OUTPUT statement. This potential for conflict is virtually eliminated by assigning priority to the commands made with the new keywords and keeping track of the intended state of the HP 3421A in an internal buffer in the HP-71B. The buffer records the current settings for:
- The HP 3421A device specifier (address)
- The degree mode for temperature conversions (C, F, K, or R)
- The gate time for the counter (0.1, 1, or 10 seconds)
- The number of digits of resolution (3, 4, or 5)
- The range (−1 through 7)
- The autozero status (on or off)
- The autorange status (on or off).

The entire instrument buffer is sent to the HP 3421A before a new reading is taken, ensuring that the instrument will be in the correct state. This way the settings requested by the new keywords in the Data Acquisition Pac will be enforced even if all the instrument settings have been altered by an OUTPUT statement in another program.

The HP 3421A can be ordered with various optional plug-in cards, depending on the needs of an application. This means that some commands will be correct for specific configurations, but incorrect for others. To facilitate rapid error detection, the instrument status is checked after each command is sent, so that problems such as invalid channel requests or ranges can be detected immediately. This saves another check that would need to be done from a BASIC program using ENTER and OUTPUT statements to talk to the HP 3421A.

The keywords provided for conversions from voltage or resistance to temperature are based on curve fits originally written in BASIC for a desktop computer. The BASIC routines provided accurate results, but with a significant speed penalty. These routines were rewritten in assembly language, providing a 20-to-1 speed improvement while minimizing the effect of round-off errors by using 15-digit internal math routines.

To complement the calculator-like friendliness of the HP-71B operating system, temperature unit conversion routines are built into the keywords. The HP-71B has a variety of system settings, such as OPTION BASE for array declarations and OPTION ANGLE for trigonometric functions. The OPTION statement was extended to include OPTION DEGREES unit. The available temperature units are Celsius, Fahrenheit, Kelvin, and Rankine. By declaring OPTION DEGREES C, the programmer specifies that the results of future temperature conversions will return Celsius degrees.

Binary Subprogram

A binary subprogram called SCAN was written to complement the 30-reading data buffer in the HP 3421A. This subprogram provides significant performance enhancements by replacing the entire command sequence and loop structure normally used in BASIC for a burst measurement into a single binary subprogram call. The subprogram requires a command string that specifies the measurement, a vector to retain the collected readings, an index that points into the vector to indicate the starting position for the readings, and an error parameter.

BASIC Programs

The BASIC programs are designed to take full advantage of the features in the HP-71B operating system, yet retain the friendly personality of a calculator. To this end, the front panel and data logging programs are designed to work with or without peripheral devices such as printers or video interfaces. The user interfaces of the various programs are designed to be consistent, so that an operator familiar with one program will feel at home with another. Many complex operations requiring a number of commands on larger computers are reduced to a single keystroke. Error handling is designed to reduce the impact of simple entry mistakes or requests for impossible measurement or control functions.

System Monitor Example

The combination of the HP-71B Handheld Computer, the HP 3421A Data Acquisition/Control Unit, and the HP 82479A Data Acquisition Pac can be used to provide monitoring and control functions in space-critical or budget-critical environments where a large system simply may not fit. The MONITOR program can not only monitor a system, but can also control the system using limit tests. Consider a production photographic laboratory with a controlled-temperature bath that must be maintained within one degree of 25°C. Two type-T thermocouples are used to monitor the temperatures. A room-temperature thermocouple is connected to channel 3 of the HP 3421A, and a bath-temperature thermocouple is connected to channel 4. The bath heater is controlled by a relay, which in turn is controlled by actuator channel 0 of the HP 3421A. The HP-71B containing the HP 82479A plug-in ROM is connected to the HP 3421A and to an 80-column video interface and video monitor as shown in Fig. 1.

In this example, the MONITOR program continuously displays the room temperature and bath temperature on the video monitor. In addition, two sets of limit tests are specified: the control limits and the alarm limits. The lower and upper control limits are set at 24.5 and 25.5°C. When the temperature falls below 24.5°C, the actuator channel is closed, turning on the heater by means of a relay. When the temperature rises above 25.5°C, the actuator channel is opened, turning the heater off. The lower and upper alarm limits are set at 24 and 26°C. If the control system fails, one of the alarm limits will be reached and the HP-71B will beep. Additional alarm limit actions could log the event on a printer or control additional actuators.

Fig. 2 illustrates the contents of the video monitor display while the photographic laboratory monitor is running.

```
                 PHOTOLAB TEMPERATURE MONITOR

Setup:            Datefile:   TESTDATA:MAIN   Time: 14:22

1 Room Temp.      21.85            I  X                 I
2 Bath Temp.      25.17            I          X         I
```

Fig. 2. *Video display for system of Fig. 1.*

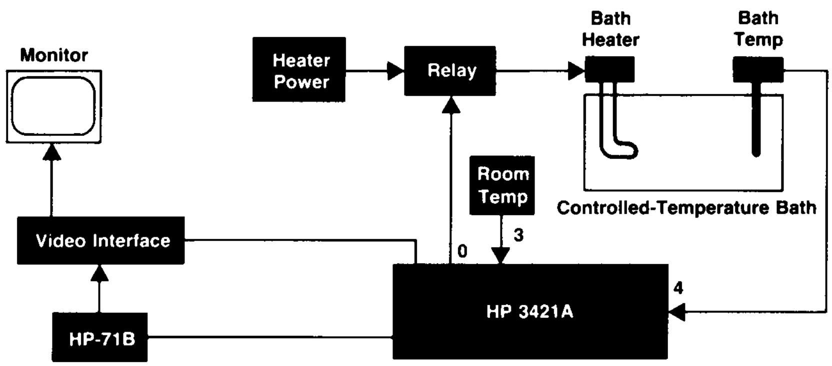

Fig. 1. *Photographic laboratory temperature monitoring system with actuator control.*

Wherever possible, the user's working environment is preserved to protect the value of working variables, files, and other data.

Unlike larger desktop computers, the HP-71B is designed to work under extremely low memory conditions while managing multiple data and program files in memory. Hence, the data logging program options are designed to work under low memory conditions. In the event of equipment failure, data is always preserved. The file update procedures to external mass storage devices are designed to protect the integrity of the file at the slight cost of processing speed. An HP-IL failure during disc access risks at most one data scan, leaving the other records intact. The data analysis and transfer programs are designed to accommodate data files with partial data, such as data from an experiment that terminated with an equipment failure or upon receiving an abort command from the operator.

The BASIC programs in the HP 82479A Data Acquisition Pac are described below:

- The FRONT program in conjunction with a keyboard overlay redefines the HP-71B keyboard, mapping the HP 3421A functions to individual keys. Additional key redefinitions combine voltage or resistance measurements with temperature linearization functions to provide complete temperature measurement functions.
- The STRIP program in conjunction with an HP ThinkJet Printer produces up to nine traces on a 1% scale. The measurement function and scale are specified for each trace. The scales for each trace are printed at the top of each page of output. Program options include measurement interval times and data storage options.
- The MONITOR program in conjunction with an HP-IL video interface provides a visual system monitor and control capability. Up to 18 traces can be presented on the video display. A trace consists of a horizontal line on the display showing a label, an actual measurement, and a 32-point scale indicating the position of the current measurement relative to specified nominal bounds. The display is designed so that the system operator can assess the state of the system at a glance, instead of having to interpret numerical readings one by one. Five limit tests can be applied to the measurement of each trace. If a test fails, one of six available limit actions can be taken.
- The SETUP program is used to define a data logging procedure. Up to 20 groups can be specified for a single data logging experiment. A group definition consists of the mea-

surement function specification, up to five limit tests, and data storage and timing specifications. The LOG program is used to execute the data logging setup. Options in the LOG program include buffered data storage and device power-down capability for extending the life of battery-powered peripherals.

- The REPORT program provides printouts of collected data, summary statistics about the data, and strip charts from collected data. These options can examine the entire file or a time segment within the file.
- The TRANSFER and MSDOSXFR programs are used to move collected data to Series 200 and Series 300 Computers or MS-DOS-based computers such as the HP 150, The Portable, or the Vectra. Files transferred to the MS-DOS computers are compatible with 1-2-3™ from Lotus™.
- The STATUS program is used to read the status registers in the HP 3421A and produce a comprehensive report listing error conditions, option configurations, and the current operating status.
- The VERIFY program provides an interactive diagnostic procedure for verifying the proper operation of the HP 3421A. The program prompts for the installation of a diagnostic block on each option board installed, and checks for proper operation with the diagnostic circuits.

Measurement Options

Twenty-one measurement functions are offered among the three main data acquisition programs. These functions correspond to the main capabilities offered by the HP 3421A combined with the temperature linearization keywords. The functions include dc volts, ac volts, direct current, two- and four-wire resistance, frequency, six thermocouple types, 2-kΩ and 5-kΩ thermistors, RTD, digital bit, and digital byte. The programs provide two- and four-wire resistance measurement options for the thermistors and the RTD.

Clearly, the BASIC programs cannot anticipate all possible measurement applications involving the HP 3421A. An additional function is included that permits the user to write a special BASIC subprogram to perform custom measurement procedures. This hook allows new measurement procedures to be created that still take advantage of the user interface and data storage facilities provided by the programs in the Data Acquisition Pac.

In addition, each function can call a conversion program for additional processing of a measurement. For instance, there is no alternating current function in the HP 82479A ROM. A simple conversion program that divides an ac voltage by the shunt resistance can provide the equivalent of an alternating current function.

Limit Tests

The MONITOR and LOG programs can perform limit tests on data collected by each function. A simple negative feedback loop can be created for temperature control by setting a limit test that turns on a heater if a temperature falls below a set level, or turns off the heater if the temperature rises above a certain level. Limit actions include a simple beep, the printing of a message, switching an actuator, enabling or disabling another measurement group (in the case of the LOG program), or the calling of a user-written program. As mentioned before, the programs cannot anticipate all of the possible actions that might have to take place in the event of an out-of-limit condition. A hook that allows the user to write a custom limit action program provides significant flexibility in system design.

Error Recovery

Most of the peripherals that are available on the HP-IL are battery-powered and not subject to the misfortunes of ac power line interruptions. Nevertheless, under some conditions a device may temporarily malfunction or cease to operate, causing an error to be detected by the HP-71B. In most instances, the execution of a RESTOREIO command is sufficient to return the interface loop to working order. Clearly, in either production or unattended long-term data acquisition applications, some form of automatic error recovery is desirable. Each of the programs in the Data Acquisition Pac calls a subprogram RECOVER when a loop problem is encountered. The recovery subprogram is sufficient to bring the system back to working order in many cases without operator intervention. Some system configurations may require different error recovery procedures than are provided. By placing a new RECOVER subprogram in the memory of the HP-71B, the user can effectively replace the one in the HP 82479A module. This hook provides more sophisticated system designs for error recovery. For example, if an HP 82402A Dual HP-IL Adapter is installed in the HP-71B, the recovery subprogram might notify a host computer connected to loop two that loop one is broken and out of service.

Acknowledgments

Nathan Zelle wrote the assembly language routines and provided invaluable contributions to the entire project. Nathan Meyers assembled the data transfer programs from pieces contributed by me and Bill Saltzstein. Many people expressed interest and offered design suggestions, making this a true "next bench" project. Notable for their contributions are Bob Botos, Jerry Hamann, and Peter Vanderheiden of the Loveland Instrument Division and Grant Garner, Dan Rudolph, and Don Ouchida.

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37 — Hierarchy Chart Language

Bruce A. Thompson

Born in Manchester, Iowa, Bruce Thompson studied computer engineering at Iowa State University and received a BS degree in 1981. He then joined HP's Greeley Division where he has worked on the software design for the HP 7974 and HP 7978 Tape Drives and the HP 88500 Disc/Tape Interface Card. He is the coauthor of two conference papers on hierarchy charts and parallel processing using microcomputers. He also wrote one paper on structured analysis. A resident of Fort Collins, Colorado, Bruce is an amateur radio operator (WB0QWS) and likes skiing, photography, and watching football.

David J. Ellis

A coauthor of two conference papers on hierarchy charts and parallel processing using microcomputers, David Ellis has worked on the software design for the HP 7978 Tape Drive and the HP 88500 Disc/Tape Interface Card since joining HP in 1983. Before that, he wrote compilers, assemblers, and linkers for Tektronix, Inc. after completing the requirements for a BS degree in computer engineering at Iowa State University in 1981. David was born on Scott Air Force Base in Illinois and now lives with his wife and two daughters in Fort Collins, Colorado. He enjoys listening, playing, and singing numerous types of music and is involved in learning how to ski without injuring himself.

43 — HP-71B ROM

James A. Donnelly

With HP since 1981, Jim Donnelly was born in Chicago, Illinois and attended Oregon State University. He completed work for a BS degree in broadcasting in 1979 and did instrumentation programming at the University of Oregon as well as running his own software consulting business before joining HP. He is now an R&D engineer and contributed to the design of the ROM for the HP 71B Handheld Computer. He is also the coauthor of three technical papers. Jim lives in Corvallis, Oregon and is a member of the Corvallis Art Guild. He likes to travel in the American West and northern Europe and enjoys music, photography, and cars.

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