①

AD-A211 312

LETTER REPORT

358

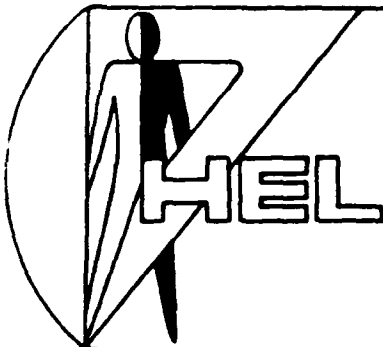## DATA ACQUISITION WITH PERSONAL COMPUTERS

James M. King
Joseph Mazurczak
Joel T. Kalb

July 1989

Behavioral Research Division
Human Engineering Laboratory
Aberdeen Proving Ground, MD 21005-5001

US ARMY HUMAN ENGINEERING LABORATORY

89 8 15 068

ABSTRACT

This report describes representative samples of the hardware and software available for data acquisition and specialized analysis on XT and AT class personal computers and relates the authors' experience with three integrated systems. For all but the most demanding acquisition tasks and the most hostile environments, we recommend that users strongly consider using a plug-in board with menu-driven acquisition software and statistical and specialized analysis packages suited to their application.

A-1

CONTENTS

DATA ACQUISITION WITH PERSONAL COMPUTERS

INTRODUCTION

Personal computers have become very popular as data acquisition devices in laboratories (Cleaveland, 1989; Leibson, 1988; Tiersten, 1988), and they are beginning to serve similar roles in some very sophisticated industrial settings (Kaplan, 1988; Malcosky, Clay, Herchline, & Kerr, 1988). Worthwhile discussions of data acquisition hardware for personal computers are available in the literature (Miller, 1986) and from several suppliers (Data Acquisition Systems, 1988; Data Acquisition Catalog, 1989), as are discussions on constructing one's own interface boards for this purpose (Tompkins & Webster, 1988).

The objectives of this report are (a) to provide an analysis of the types of hardware and software available for data acquisition and specialized analysis on XT and AT class personal computers, and (b) to relate our experience with several of these systems.

RESULTS AND DISCUSSION

Acquisition Hardware

There are several types of hardware available to support data acquisition and control on personal computers. Each type has its unique advantages and disadvantages. Communications-based acquisition devices, or front ends, and plug-in boards will be discussed in turn. While much of this discussion focuses on speed, bear in mind that accuracy is at least as important a factor in many applications (Cleaveland, 1989).

Communications-Based Acquisition Systems

Communications-based data acquisition systems differ from the systems that use plug-in boards in that the analog-to-digital and digital-to-analog conversion processes occur in an interface box that can be located some distance from the host computer in hostile environments. Some of these systems are capable of supporting more than 100 data channels, but they can start small and be expanded later. The front ends, which do the actual conversion work, are able to communicate with virtually any type of computer that has a RS-232C, RS-422, RS-485, or IEEE-488 port. Available sampling rates are in the range of seconds per sample to 100,000 samples per second, although these data are typically communicated to the computer at 9600 baud or less. Many of these systems are also able to communicate using a modem. These systems provide good signal isolation to the computer, and they are particularly suited to operation in harsh industrial or field environments that would be unsuitable for typical computers. This level of flexibility and ruggedness comes at a price. Typical costs for these systems are about $300 per data channel. Systems of this type are also much less likely to be supported by menu- or command-driven control programs such as the ones described later in this report. Thus, a

considerable programming burden is likely to be placed on the user. This hardware is available from a variety of sources, including CONTEC and OMEGA.

Plug-In Boards

Two types of plug-in boards are available for personal computers--those that support direct memory access (DMA) and those that do not. DMA is the process of sending data directly to the personal computer's memory. Installation of these boards is a simple process, and most of them are supported by the software packages discussed later in this report. Typically, these boards will use some sort of external isolation and junction box, attached to the interface board by a short length of cable, to join the input signal lines to the interface boards. Thus, the computer is commonly located in the same environment as the sensors. While this would generally negate the operation of such systems in harsh environments, ruggedized computers are available (Industrial Computer Source Book, 1989) for operation in hostile conditions. These boards cost between $125 to $200 per channel depending on such features as data rates supported, number and types of channels, and functions provided. Thus, in considering which board to purchase, you will need to determine the number of analog-to-digital, digital-to-analog, and digital-to-digital channels you require; the nature of the signals to be provided to each channel; and the sampling rate you require. You should note that many of these boards support control functions through their digital-to-digital and analog-to-digital channels that enable your computer to alter some aspect of the environment in response to either the incoming data stream or to a predetermined sequence of events.

DMA boards have the fastest data acquisition rates available for personal computers (Porter, 1986). These boards are capable of sampling rates in the range of 100 kilohertz (KHz) on XTs, 150 KHz on 80286 ATs, and 250 KHz on 80386 machines, although user-written programs accessing special driver subroutines may be required to achieve these rates. More mundane rates, between 900 to 2,000 hertz (Hz) are supported by the control programs discussed later with more or less real-time display of the data collected.

Some interface boards lack this DMA feature. These are the lowest priced boards, but they will probably be unable to keep up with any but the slowest of signals, particularly when multiple channels are involved. Available data rates, totaled over all channels, are 7 to 10 times slower than DMA rates.

IEEE-488, also known as the general purpose interface bus (GPIB) standard can be implemented on personal computers using specialized cards available from several manufacturers. These cards and their associated software make it possible for personal computers to send data to and receive data from devices such as real-time analyzers, laboratory instruments, and plotters that use this standard. Although our experience with such boards is limited, we can report that, while the installation of the board is easy, its use is a nontrivial task.

There is a wide variety of sources for this type of hardware. These sources include Analog Devices, CONTEC, Data Translation, the Industrial Computer Source Book Company, MetraByte, OMEGA, and Strawberry Tree Computers.

In selecting one of the types of hardware described earlier, several questions must be asked:

4

Will the system support the number and types of input and output channels I need at the required sampling rate?

Is the system compatible with my computer?

Will the board fit into my computer? (Note that some boards can be so wide that they interfere with neighboring boards.)

Do I have suitable slots available in my computer? (Note that some boards will require an 8-bit slot, while others require a 16-bit slot. Is one available? Further, some computers, such as Zenith 386 upgrades, contain several nonstandard slots that will not accommodate cards with descending lower edges.)

To answer these last two questions, remove the cover of your computer and compare pictures of the boards you propose to use with the appearance and number of slots available in your computer. These problems can sometimes be overcome by using bus expansion boxes.

Acquisition Software

Several types of software are available to control the hardware described in the preceding section. These can be grouped under three headings--menu-driven, command-driven, and subroutine-based. This ordering is generally from easiest to use to hardest to use; most expensive to least expensive; and least demanding to most demanding of user knowledge, expertise, and time. In some cases, a software package is available, both in a generic version from its developer and in a hardware-specific version from the board supplier. All the acquisition and control boards require some sort of control software. The best type for a particular application depends on the details of your requirements and on your particular skills. In selecting software, you will need to consider ease of use, adaptability, processing speed, and cost (Leibson, 1988).

Menu-Driven Software

Menu-driven software packages are recommended for all applications that they are able to support because they can put your system into service quickly and easily and because they place far fewer demands on the user than do the other types of software packages. This is not to say that using these programs is always a simple task. A successful initial installation may well require that you deal with such arcana as switch settings for memory base addresses and register base addresses (taking care to avoid conflicts with other hardware already installed), installation of specialized device drivers, not to mention creation of subdirectories, batch, and configuration files.

Laboratory Technologies' LabTech Notebook (1987) (cost $995.00) is a particularly usable example of the menu-driven software family. This package operates in two modes. In the normal mode, it supports more or less the real-time display of data to the screen while collecting the data, and it will support total data rates of 300 Hz on an XT, 1,000 Hz on an 8-MHz AT, and 3,000 Hz on an 80386-based machine. In the high speed mode, the DMA rates discussed above are supported, although real-time display of the data to the screen is not available. Notebook also supports nearly all the digital-to-analog, analog-to-digital, and digital input/output

functions that may be built into a particular board. Thus, this package is not only able to acquire data, but to control external processes based on both predetermined parameters and on the value of one or more input channels. Sophisticated real-time calculations on input channels are also supported. This software is available in both generic and board-specific versions. The generic version includes software drivers for all the boards supported by Notebook and is available from the manufacturer and from several of the other companies listed in the Appendix. The board-specific versions are available from the suppliers of the boards and commonly include drivers only for that one brand of board. Notebook supports the DATAQ Wave Form Scroller card. Notebook is copy-protected using a hardware key. The data files produced by this package are readily exportable to a variety of analysis packages.

Asystant+ (1987) from MacMillan Software Company (cost $895.00) is another menu-driven acquisition package. It is a little more demanding of memory than Notebook and does not function well in a machine in which terminate and stay resident programs have been loaded into random access memory, or in which more than the minimum number of device drivers have been placed into the CONFIG.SYS file. Its control functions are less extensive than Notebook's, but it offers additional analysis capabilities. For some applications, Asystant+ could serve to acquire and to analyze the data from experiments. Like Notebook, Asystant+ supports the DATAQ Wave Form Scroller card and a wide variety of acquisition and control boards. Copy protection is provided by a key disk system.

The Snapshot storage scope program (1988) from HEM Data Corporation (cost $495.00) permits the use of the computer as a digital storage oscilloscope and limited data acquisition system. It controls several of the MetraByte, Data Translation, and Analog Devices data acquisition boards; records input to disk files; displays as many as four channels of data on a graphics monitor; provides offset, zoom, and cursor-driven time and voltage displays; and can replay previously acquired data files to the screen. It supports analog and digital output. The maximum sampling rate available is the maximum sampling rate of your board divided by the number of channels sampled. This software has proven to be particularly useful in testing and calibrating data acquisition and control systems. Snapshot is not copy-protected.

Command-Driven Software

Asyst (Up and Running with Asyst 2.0, 1987) from MacMillan Software Company (cost $2,095.00) is a language for scientific analysis with an overlay of data acquisition and control functions. These functions are less extensive than Notebook's, but it offers considerable additional analysis capabilities. Asyst supports a fairly extensive list of data acquisition and control boards. For some applications, Asyst could serve to both acquire and to analyze the data from experiments. However, the effective use of this software requires that the user become proficient in a new programming language, a process that typically requires a considerable investment of time and energy. Copy protection for Asyst is provided by a hardware key.

Subroutines in Specific Languages

We have encountered this type of control software most often with the Data Translation ATLAB package (cost $495.00) for their acquisition and control boards, although similar packages are available for boards from other manufacturers. While these same boards are generally also supported by the other software types described earlier, the full speed capabilities of the boards may not be available through such packages. These subroutines may be provided in libraries for FORTRAN, C, Pascal, or BASIC, depending on the board in question. It is very important in using these packages to ensure that you have the appropriate brand and version of the compiler or interpreter for the subroutines that you propose to use. This type of approach to control software clearly gives the user the maximum flexibility in using the boards, but it is entirely beyond the abilities of the typical user who is not an expert programmer. Even for the skilled programmer, it will require time to create a usable control application, because a truly functional acquisition and control program is also generally a fairly long and involved piece of software.

There are advantages and disadvantages to each of these approaches to software control of data acquisition. The menu-driven systems are the easiest to set up, and they offer the best user interfaces. However, they usually will not allow you to use the full capabilities of the highest speed boards, and they may be unable to meet some particularly stringent user requirement. Command-driven systems, such as Asyst, offer greater flexibility at the expense of considerably degraded ease of use. They nearly amount to programming languages in their own right. These packages place a considerable burden on the user. The most flexible, but the most difficult control approach to implement is writing programs in languages such as C or Pascal that call for specialized control subroutines. This approach places an extreme technical burden on most users. A programmer must usually be available to implement such an approach.

Specialized Analysis Software

RS/1 (1986) from BBN Software Products Corporation (cost $2,000.00) is in essence, the scientists' answer to more business-oriented spreadsheet programs such as Lotus 1-2-3 and Quattro. It offers extensive table- and model-building capabilities, outstanding two- and three-dimensional graphics, a superior function-fitting routine, statistical analysis capabilities, and a high quality driver for Hewlett-Packard flatbed plotters. File import and export operations are relatively easy to accomplish. RS/1 functions are available either from the command line or through an interactive prompt and reply menu process. A particular advantage of this package is that it is available in mainframe, minicomputer, workstation, and personal computer versions, all of which use a common user interface. Copy protection for the personal computer version is through a hardware key.

DADiSP (1987) from DSP Development Corporation (cost $795.00) is a spreadsheet for wave form analysis. It supports arithmetic, trigonometric, calculus, statistical functions, Fourier analysis, peak analysis, signal editing, signal averaging, signal processing, wave form generation, and data file import and export. The results of the signal manipulations are displayed on the screen in a sequence of windows-- one for each manipulation. This is a program for specialized needs, but if you need it, you probably need it badly. Copy protection is provided by SuperLock.

A typical u~~s~~ r will also find that one of the full-featured statistical programs for personal comp   rs, such as SYSTAT, SPSS-PC, or BMDP, will be necessary to complement th~~...~~e more specialized analysis packages. A detailed discussion of these packages is beyond the scope of this report. Costs for such packages run from $900.00 to $2,000.00, depending on the modules and other options selected.

Hardware Accessories

The *DATAQ Wave Form Scroller* card from DATAQ Instruments, Inc. (cost $795.00) is a specialized video display card that enables suitable monitors to display as many as 4,000 points of data per second on an AT class machine. This effectively enables your monitor display to keep pace with the incoming data stream for all but the fastest data acquisition applications.

Mathematics coprocessors, such as the Intel 8087 for 8086/8088 XT class machines, the Intel 80287 for AT 80286 class machines, and the Intel 80387 for AT 80386 class machines, usually will not directly affect the rate of data acquisition. However, they will improve the speed of many of the data analysis programs considerably . Note that these chips come in a variety of speeds, not all of which are correct for a particular machine.

Extended and expanded memory will not usually alter the speed of data acquisition. Extended memory can, however, serve to facilitate data analysis

(a) by providing a RAM disk to enhance manipulation of large data files,

(b) by forming a disk cache to speed reading and writing of files,

(c) or by serving as a print buffer,

(d) while expanded memory conforming to the Lotus/Intel/Microsoft Expanded Memory Specification can increase the size of spreadsheets that can be manipulated by some analysis programs, such as Lotus 1-2-3.

Any personal computer used as a data acquisition instrument is eventually going to require some form of removable mass storage for archiving the data files. Removable mass storage media can range from 360-kilobyte floppy disks, through 1.2- and 1.44-megabyte floppy disks, 20-megabyte removable cartridges, such as those manufactured by IOMEGA Corporation, to tape-based systems of even higher capacity. The device selected should reflect the size of the data files that are likely to be produced by your application and the number of data files that you will need to keep together. Generally, tape-based systems are not recommended because they do not readily support random file access.

Current Experiences at BRD

MetraByte DAS 16F With LabTech Notebook and RS/1

The specific application in this case was to record heart rate, respiration, eye blink, aiming point in azimuth and elevation, and trigger pull in subjects using a simulator for such man-portable weapons as the M16 and the AT4. The physiological

data are processed through a Grass data recording system before being passed to the MetraByte DAS 16F (cost $1,115.00), while the azimuth and elevation data are derived from signals from a CCD camera mounted on the weapons that have been processed through custom-built hardware that generates time-varying voltages corresponding to the azimuth and elevation coordinates of an infrared light sight source as seen by the camera.

The DAS 16 board is equipped with a 12-bit converter, which provides resolution to one part in 4096. For analog-to-digital conversions, it supports either eight channels of differential input over plus or minus 10, 5, 2.5, 1, or 0.5 volts or 16 channels of single-ended input over input ranges of 0 to 10, 5, 2.5, or 1 volts. This board also has two 12-bit digital-to-analog output channels, a three-channel programmable interval timer, and 8 bits of digital input/output. On this particular model, gains are set using switches on the board, although a model that allows for software-selectable gains is available. All signals are presented to the board as DC voltages by way of a STA-16 Screw Terminal Board (cost $115.00) and a C-1800 cable (cost $25.00). In this application, each channel is typically sampled at 60 Hz. This in no way pushes the capability of this board.

LabTech Notebook has proven to be effective in acquiring the data for this application. It was easy to install, to configure, and to use. In our hands, the entire setup process required only a few hours from the time we opened the boxes until data collection was able to begin. For specialized applications, Turbo Pascal, C, and FORTRAN drivers to support this board are also available from the MetraByte.

The RS/1 package is used to analyze the data collected by Notebook and to prepare graphs. RS/1, as noted earlier, is a scientific answer to such spreadsheet programs as Lotus 1-2-3 and Quattro. It includes many built-in statistical and mathematical capabilities that are not present in the other packages.

The installation and integration of a system such as this is a straightforward process, but it does require a sophisticated user. As long as the computer is not loaded down with too many interface boards or device drivers, an individual will not encounter many problems.

Data Translation 2821-F With C Subroutines

The application in this case is to capture acoustical signals, to edit them, and to replay them with high fidelity. Typically, only a single channel of information is captured at a time. Sampling rates in this application are up to 130,000 Hz of continuous throughput, although this is achieved only under MS-DOS 3.21 or later.

The 2821-F board (cost $1,995.00) is equipped with a 12-bit converter, which provides resolution to one part in 4096. For analog-to-digital conversions, it supports either eight channels of differential input over plus or minus 10 volts or 16 channels of single-ended input over input ranges of 0 to 10 volts. This board also has two 12-bit digital-to-analog output channels, a three-channel programmable interval timer, and 16 digital input/output lines in two ports. On this particular model, gains are software-selectable. Signals are routed to and from the board through a DT707 Screw Terminal Panel and its attached cable (cost $179.00).

Preliminary work revealed that Notebook was able to support the analog-to-digital capture rates required, but was unable to achieve an acceptable digital-to-

analog conversion rate on playback. In order to achieve the required playback rate, it was necessary to incorporate the ATLAB subroutines into a custom-written Microsoft Version 3.0 C language program. This is an involved undertaking, and many days were required to produce a usable program. This software development process places considerable technical demands on the potential user, but may be required to achieve the highest levels of throughput. Data Translation sells the ATLAB subroutine library. a package that controls the 2821F's operations, to assist in the process. Howeve., if a skilled programmer is available, this approach of developing your own control program may be very reasonable for less demanding applications as well.

The combination of the 2821F board and the locally written control programs has performed well, but a search is currently underway for a board with a 16-bit analog-to-digital and digital-to-analog converter, operating at comparable rates in order to improve the quality of the acoustical signals produced. The current standard digital audio devices, digital audio tape recorders and compact disc players, use 16-bit converters, which provide a resolution of one part in 65,536.

Data Translation 2821 With LabTech Notebook and DADiSP

The application of this system is to capture and analyze electroencephalogram (EEG) signals for P300-related events. This requires that the system capture multiple channels of EEG data, which have been processed through a Grass system, and that it capture relevant stimulus-timing information. Channels are routinely sampled at 60 to 100 Hz. Setup and integration of Notebook and the 2821 board (cost $1,345.00) proceeded quickly. The characteristics of the board were described in the preceding section. The DADiSP package is particularly interesting, as this spreadsheet for wave forms is uniquely adapted to this type of research. Although work with the integrated system, which is intended to replace an aging Nicollet MED-80, is only beginning, it appears that this combination will be effective in practice.

CONCLUSIONS

This report has described representative samples of the hardware and software available for data acquisition and specialized analysis on XT and AT class personal computers, and related our experience with three integrated systems. For all but the most demanding acquisition tasks and most hostile environments, we recommend that users strongly consider using a plug-in board, menu-driven acquisition software, and statistical or other specialized analysis packages suited to their application. When a word processor is added to the system, personal computers can acquire, process, analyze, plot data, and prepare the resulting reports. Readers should be aware that newer versions of the software and hardware described in this report are now being shipped by vendors. The characteristics of the hardware and software with which the authors have had experience are summarized in Tables 1 and 2. Sources for the hardware and software items discussed in this report are given in the Appendix.

Table 1

Characteristics of Data Acquisition and Control Boards Used by BRD

	DAS 16F	DT2821F	DT2821
Cost	$1,115 (board) $ 140 (terminal and cable)	$1,995 (board) $ 179 (terminal and cable)	$1,345 (board) $ 179 (terminal and cable)
Resolution in	12 bit	12 bit	12 bit
Channels in	8 differential + or - 10, 5, 2.5, 1, .5 V or 16 single-ended 0 to 10, 5, 2.5, or 1 V	8 differential + or - 10 V or 16 single-ended 0 to 10 V, factory set	same as DT2821F but jumper-selectable
Channels out	2 12 bit 0 to 5 V	2 12 bit 0 to 5, 0 to 10, + or - 2.5, 5, 10 V	same as DT2821F
Timer	3-channel programable	1 programable	1 programable
Gain setting	Switches on board	programable 1, 2, 4, 8	same as DT2821F
A/D, D/A rate	100,000 Hz - DMA 4,000 Hz - non-DMA	150,000 - DMA in 130,000 - DMA out (1 channel) 260,000 - DMA out (all channels)	40,000 - DMA in others same as DT2821F
Digital I/O	8 nes, 4 in, 4 out	16 lines	16 lines

Table 2

Characteristics of Software Used by BRD

	Cost	Type	Acquisition	Control	Analysis	Hardware Supported	Copy Protection
LabTech Notebook	$995	Menu-driven acquisition and control	extensive	extensive	limited	extensive	hardware key
MacMillan Asystant+	$895	Menu-driven acquisition and control	extensive	moderate	extensive	extensive	key disc
Snapshot	$495	Menu-driven digital oscilloscope	moderate	none	moderate	limited to MetraByte, Data Trans., Analog Dev.	none
MacMillan Asyst	$2,095	Command-driven analysis program with an extensive overlay of acquisition and control functions	fairly extensive	moderate	extensive	extensive	hardware key
Data Translation ATLAB	$495	Subroutine library for acquisition and control	extensive	extensive	limited	Data Trans. only	none
RS/1	$2,000	Scientific spreadsheet	none	none	extensive	NA	hardware key
DADiSP	$795	Wave form analysis spreadsheet specialized for this application	none	none	extensive	NA	SuperLock

REFERENCES

Asystant+. (1987). New York, NY: MacMillan Software Company.

Complete book of discount software. (1988). Stamford, CT: OMEGA Engineering, Inc.

Cleaveland, P. (January 1989). Data acquisition and data logging technology update. I&CS, 31-35.

Data acquisition and control for IBM PC/XT/AT, PS2, microchannel and Apple Macintosh computers (1989). 19. Tauton, MA: MetraByte Corporation.

DADiSP worksheet manual. (1987). Cambridge, MA: DSP Development Corporation.

Data acquisition catalog. (1989). Marlboro, MA: DATA TRANSLATION.

Data acquisition systems. (1988). Volume 26. Stamford, CT: OMEGA Engineering, Inc.

Factory/Lab automation interface boards for IBM PC/XT/AT and compatibles. (1989). San Jose, CA: CONTEC Microelectronics USA, Inc.

Image processing catalog. (1988). Marlboro, MA: DATA TRANSLATION.

Industrial computer source book. (1989). San Diego, CA: The Industrial Computer Source Book Company.

Kaplan, G. T. (1988). What are your control options? A selection guide to system alternatives. Instrumentation and Control Systems, 61(6), 45-48.

LabTech Notebook Version 4.1. (1987). Wilmington, MA: Laboratory Technologies Corporation.

Leibson, S. H. (9 June 1988). Laboratory-automation software. EDN, 115-126.

Malcosky, N. D., Clay, P. A., Herchline, L. E., & Kerr, G. H. (1988). Personal computer field site data acquisition system operating manual. Topical report January 1986-December 1987. Colombia, OH: Columbia Gas System Service Corporation.

Miller, E. M. (1986). Digitizing analog data. PC Tech Journal, 4(5), 52-67.

PC bus compatible products. (1988). Norwood, MA: Analog Devices.

Pillay, G., & Cokal, E. J. (1987). Configuration and operation of a PC-based waveform scroller/data acquisition system. Los Alamos, NM: Los Alamos National Laboratory.

Porter, R. (1986). DMA, data acquisition and the personal computer. Digital Design, 16(10), 33-36.

RS/1 Version 12.2. (1986). Cambridge, MA: BBN Software Products Corporation.

Snapshot storage scope user's manual. (August 1988). Southfield, MI: HEM Data Corporation.

Tiersten, S. (1988). PCs make it easier to collect and analyze data. Electronic Business, 14(19), 115-116.

Tompkins, W. J., & Webster, J. G. (Eds.) (1988). Interfacing sensors to the IBM PC. Englewood Cliffs, NJ: Prentice Hall.

Up and running with Asyst 2.0. (1987). New York, NY: MacMillan Software Company.

APPENDIX

SOURCES

SOURCES

Analog Devices
One Technology Way
P.O. Box 9106
Norwood, MA 02062-9106
617-329-4700

BBN Software Products Corporation
10 Fawcett Street
Cambridge, MA 02238
617-491-8488

CONTEC Microelectronics U.S.A. Inc.
2010 N. First Street, Suite 530
San Jose, CA 95131
800-888-8884

DATA TRANSLATION
100 Locke Drive
Marlboro, MA 01752
508-481-3700

DATAQ Instruments, Inc.
825 Sweitzer Ave.
Akron, OH 44311

DSP Development Corporation
One Kendall Square
Cambridge, MA 02139
617-577-1133

HEM Data Corporation
17025 Crescent Drive
Southfield, MI 48076
313-559-5607

Industrial Computer Source
P.O. Box 23058
5466 Complex St., #208
San Diego, CA 92123

IOMEGA Corporation
1821 W. 4000 S.
Roy, UT 84067
801-778-3000

Laboratory Technologies Corporation
255 Ballardvale Street
Wilmington, MA 01887
617-657-5400

MacMillan Software Company
630 Third Avenue
New York, NY 10017
212-702-3241

MetraByte Corporation
440 Myles Standish Blvd.
Tauton, MA 02780
508-880-3000

OMEGA Engineering, Inc.
One Omega Drive
Stamford, CT 06907
800-826-6342

Strawberry Tree Computers, Inc.
160 South Wolfe Road
Sunnyvale, CA 94086
408-736-3083