UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

A PC-BASED SEISMIC DATA ACQUISITION AND PROCESSING SYSTEM

by

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1. INTRODUCTION

A seismic data acquisition and processing system has been developed based on the IBM PC-AT technology. It was demonstrated informally at the PC session of the 1987 Fall AGU Meeting in San Francisco, and will be presented formally in the 1988 Fall AGU Meeting (Lee, Tottingham, and Ellis, 1988). Our goal was to build a simple and inexpensive system to digitize up to 64 analog seismic signals, detect and locate seismic events, and save the digital waveform data on mass storage. We believe that such a seismic data acquisition and processing system has many applications in seismology, especially for small local seismic networks.

In this report, we will discuss our design philosophy and development history, the hardware requirements, and the currently available software. While discussing the actual hardware and software used in our system, we will refer to many commercial products. Alternative products are also mentioned whenever possible.

The software for our PC-Quake system has been developed by both USGS staff and non-USGS scientists using commercially available software as much as possible. Therefore, not all of the software used in our system is in the public domain. However, these outside scientists have agreed to let us incorporate their executable code in our application software free of charge on an experimental basis. The required commercial software can be purchased separately. In this open-file report, we release the executable software (excluding that which must purchased commercially), and the source code written by the USGS staff. These software are available on two standard 5.25 inch floppy diskettes.

The PC-Quake system was developed to collect data for a non-USGS funded project. Users must be warned that the current edition, Version 2, PC-Quake software (released with this Open-File Report) still contains some "bugs", and we can not provide any technical support because resources within the USGS are limited. Although the programs in this disk have been tested, <u>the U. S. Geological Survey cannot guarantee that they will give accurate results for all applications or that they will work on any PC computer system</u>.

A revised version of our PC-Quake system (including several additional programs for off-line data processing and analysis by our outside collaborators) and a documented user manual will be published under the auspices of the Working Group on Personal Computers of the International Association of Seismology and Physics of the Earth's Interior, and is scheduled for April, 1989. It will be available to the public (at a nominal cost) through the Seismological Society of America (Lee, 1989).

2. DESIGN PHILOSOPHY AND DEVELOPMENT HISTORY

In the past 20 years, the first author has been involved in seismic networks, especially in data acquisition and processing (Lee and Stewart, 1981). Many computerized systems have been developed for seismic data acquisition and processing. The usual approach is to select the computer hardware first and then write the software. Because most designers would like their systems to do many things, it usually takes many years to complete a system. Unfortunately, the computer hardware is often obsolete by then.

Until the advance of personal computers, all commercially available computers had proprietary, or "closed", architectures. It was difficult for others to build and integrate additional hardware, and to move software from one computer to another. We could not benefit much from previously designed systems because the hardware was different, and software peculiar to one system was generally not useful on another. Consequently, seismologists keep on developing new data acquisition and processing systems. This situation was drastically changed in 1981 when IBM introduced a personal computer with "open" architecture that became an industry standard. We now have standard hardware and software to build upon. At present, there are over 20 million IBM PC and compatible computers in use, and several million more are added each year.

A few years ago, Al Lindh of the USGS bought an analog-to-digital board for an IBM PC from Data Translation, Inc.

After many months, he gave this DT2801 board to the first author, hoping that the board could be used for seismological purposes. Lee realized that it is not trivial to start something new, because he knew that many seismic data acquisition systems had been taken several man-years or several tens of man-years to complete. So he just let the A/D board sit. However, it started to bother him that a piece of hardware was idle, and he did not have the resources to make use of it. In early 1987, he met Jimmy Wong, who had just completed his master's degree in computer science, and had worked several years in data communication. Since Wong was looking for a job, Lee persuaded him to investigate this A/D card without pay until he found a job. After a few weeks of hard work, Wong demonstrated that with this A/D card, a PC could be used for seismic data acquisition and processing. However, by then, Wong found a job and had to terminate the collaboration.

In April of 1987, John Rogers of the USGS needed some means to collect seismic data locally in Yakutat, Alaska because the USGS could not afford to telemeter the data to their central recording site at Palmer, Alaska. Lee suggested a PC-based system and provided the necessary hardware for Rogers. Based on what Jimmy Wong had developed and with minor help from Willie Lee, Rogers completed a prototype system and headed to Alaska in the summer of 1987. This system handled only 8 channels, and saved 30 seconds of digitized waveform data each time a seismic event was detected. Double buffering and DMA transfer were not supported in hardware, so the data acquisition stops for a few seconds after each event.

In the summer of 1987, the first author obtained funding to conduct a quarry source experiment from the Defense Advanced Research Projects Agency. The original plan was to use existing USGS seismic recording equipment to collect the data. However, it soon became evident that our existing recording equipment did not have the flexibility and real-time capability in the field. In order to do this with minimal funding, Lee recognized the necessity for developing a reliable seismic data acquisition system for field use quickly and inexpensively. Because funds were not available to purchase the necessary hardware for development and testing, Lee persuaded another USGS group (Dave Harlow and Randy White) to pool their resources together, and the necessary equipment was purchased.

Without direct funding, the design philosophy is of necessity very different from the usual case. Instead of an elaborate system that does many things, the goal was a simple system that used standard hardware and required writing only a small amount of software. A design using IBM personal computers (PC's) was selected because they were the most common computer, low cost, many off-the-shelf peripherals, thousands of commercially available software, and "open" architecture. Such a system can grow in the future as the PC technology advances, and will not be obsolete in the near future.

Based on Wong's and Rogers' work on the PC and after consulting with the engineers at Data Translation, Inc., Lee recognized that a PC/AT would be needed to handle more than 8 channels and to perform additional functions. He quickly designed the present system using a more advanced A/D board (DT2821 by Data Translation, Inc.) and assigned most of the software development to his summer assistant, Dean Tottingham. By the end of the summer of 1987, Tottingham and Lee (with help from Will Kohler, John Rogers, Carlos Valdes, and Kip Wyss) had the present hardware system running on Version 1 of a program which they called MDETECT.

Tottingham returned to school in the fall of 1987, and Lee continued to test the hardware and software. In early 1988, Lee established a 16-channel seismic network at the Kaiser Permanente Quarry, telemetering the analog data back to Menlo Park via two voice-grade phone lines (in a manner similar to the USGS Calnet). The newly developed system was put to actual test: an IBM PC/AT was used in conjunction with the DT2821 A/D board to digitize the incoming seismic signals at 100 samples per second and to display all the digitized traces on a monitor screen in real time. Seismic signals were monitored, and if an event was detected, the digitized waveform data were saved on the hard disk, first P-arrival times were automatically determined, and the event was located and displayed.

The event triggering algorithm is based on short-term and long-term averages and is due to John Rogers. The automatic picking scheme is based on Allen (1978) as coded by Will Kohler.

Event location is based on a modified version of the HYPO71PC earthquake location program by Lee and Valdes (1985). In order to develop the PC-Quake system with limited available resources, we have used commercially available software for A/D operation, screen management, printing, and graphics development. We modified existing Fortran codes for picking and location, and wrote the on-line control program mostly in C. Some macro assembler language code were written for execution speed. Most of the off-line processing and analysis programs were written in Fortran. The source code were compiled using Microsoft compilers and linked with library routines provided from commercially available software and our outside collaborators.

One unique feature of our PC-Quake system is that the seismic signals are displayed in real time. None of the existing computerized seismic data acquisition systems that we know of display all the seismic signals visually in real time. We believe that it is very important to be able to see all the seismic signals in real time (similar to the Geotech Develocorder film system), especially in an active field experiment. This allows us to quickly identify if any seismic equipment is not functioning properly, and to visually check if the system is detecting events correctly.

In June, 1988, Dean Tottingham returned to work for the USGS during the summer. His first priority was to correct the "bugs" discovered in Version 1 of MDETECT after several months of actual use. This is not surprising as any useful computer program will contain many "bugs", and some of them may not be discovered an eliminated until after many years in use. Tottingham also wro the XPLAY program to play back the digital waveform data quick and easily. Lee recognized the need for programs to perform off-line data processing and analysis, and encouraged a visiti student, Carlos Valdes, to develop some of them.

Although 16 channels is sufficient for many seismological applications, ability to handle more than 16 channels of seism data is often required. Therefore, Jim Ellis was persuaded to help increase channel capacity. After exploring alternatives studying the DT2821 A/D board, Ellis recognized that an extern multiplexor board could be built to handle multiples of 16 channels, provided a minor modification is made on the DT2821 board (Ellis, 1988).

The external board consists of 16 four-to-one analog multiplexor integrated circuits. The outputs of these multiplexors are connected to the 16 analog inputs on the A/D board. Internal multiplexed addressing of the DT2821 A/D boar is done by a synchronous four-bit binary counter. The externa multiplexors are controlled by another four-bit synchronous counter cascaded from the internal counter. Each time the internal multiplexor completes a scan of 16 channels, the external counter is incremented by one to select a new set of channels to be presented to the A/D board. The present circui can select from one through four sets of 16 channels so that 1 32, 48, or 64 channels may be digitized. In principle, this expansion scheme can grow infinitely limited only by the digitizing rate of the A/D and the processing speed of the computer. Note that although the internal multiplexor can be programmed to digitize any number of channels from one through sixteen, the external device will only work if the internal A/D number is set to sixteen.

In August, 1988, Ellis demonstrated that our PC-Quake system could handle 64 channels in hardware. However, extensive improvement and additional software must be made to handle that many channels. In other words, we must write additional software to keep track of the external multiplexing of incoming signals, and we must speed up the existing software to keep up with a higher data rate.

3. REQUIRED HARDWARE AND SOFTWARE

The PC-Quake system consists of two identical units: one for on-line data acquisition and processing, and one for off-line data processing and analysis. The off-line unit also serves as a backup for the on-line system to minimize data loss in case of a hardware failure. Actually, the off-line data processing and analysis could be performed on any IBM PC or compatible, such as a PC, XT, AT, 386, or PS/2. The on-line unit must be an IBM PC/AT or compatible using the Intel 80286/80287 microprocessors. Although in theory a 80386 PC with an AT-type bus could be used, we have not tried it in practice. Hardware and software components of the PC-Quake system are described below.

(1) PC/AT basic system.

We have used an IBM PC/AT model 339, with 8 MHz 80286 CPU, a 80287 Math Coprocessor, 512 KB RAM, one 1.2 MB floppy drive, one 30 MB hard disk, one serial port, one parallel port, and enhanced keyboard.

IBM PC/AT compatibles that we or our collaborators have tried are:

(a) 286 Premium AT (with all the above stated items) by AST Research, Inc.

(b) Deskpro 286 (with essentially the same items) by COMPAQ.

(c) Everex AT compatible (with essentially the same items).

(c) Compaq Portable II (great for short field work).

We recommend a high-quality, 100% IBM PC/AT compatible computer be used. The reason is simple: the PC/AT used in the on-line PC-Quake system must be working continuously all the time.

(2) Memory Extension.

We need a minimum of 768 KB of extended memory for buffering the data from the A/D board. We have used an AST Advantage Premium multifunction card with 1 MB RAM, one serial and one parallel port. The serial and parallel ports on this card are not used at present, but it is nice to have them handy.

If you use a Compaq Deskpro 286 or Portable II, then you don't need this card, because you can put more RAM on the motherboard (2.64 MB on Deskpro 286, and 2 MB on Portable II). We have also used an Everex Magic 16 multifunction card with 2 MB RAM.

One must configure the system memory properly: 640 KB for the base memory, and all the extra memory (at least 768 KB) as extended memory. Do not use any expanded memory card or configure any RAM as expanded memory.

(3) Monitors

We often use dual monitors: one color and one monochrome for ease of operation and development. We configure the PC/AT as a single monitor system (EGA color or CGA color), and just add the Hercules card and monochrome monitor without telling the PC/AT.

This way, you can upgrade an existing color system quickly or return it to color without resetting switches and re-configuring your system. Although the Compaq Portable II has a monochrome monitor, it behaves as a CGA color system. Therefore, you must add the Hercules card and monochrome monitor to set it up as the on-line data acquisition and processing unit.

We have used an IBM Enhanced Color Adapter and IBM Enhanced Color Monitor. An alternative that we have tried is a Tecmar EGA Master card and a NEC Multisync monitor. Our collaborators have used either a Vedio 7 EGA card or an AST 3g EGA card connected to a NEC Multisync monitor. These parts should be ordered with your basic PC/AT system, and most computer stores have them.

We have also used a Hercules Graphics Card Plus with an IBM Monochrome monitor. You can get this pair or similar ones from most computer store. We have tried a so called "Hercules" compatible card, but it does some funny things occasionally. The real Hercules card is required for the PC-Quake system because you need the software that comes with the Hercules card. We recommend a high-quality monochrome monitor, especially if you take the system to the field under bright sun light.

Dual monitors are optional. For on-line data acquisition and processing, you can get by with just one monitor, and it must be a monochrome monitor connected to a Hercules Graphics Card. In this case, you configure your system as a monochrome system. For off-line data processing and analysis, you can also use a single monitor system: either monochrome with Hercules card or EGA, but an EGA system is nicer because of color graphics capabilities.

(5) A/D Board

The PC-Quake system requires a Data Translation DT2821 High-speed Analog to Digital I/O Board, Model DT707 Screw Terminal Panel, and ATLAB software (SP0143). All these parts may be ordered from Data Translation, Inc., 100 Locke Drive, Marlboro, MA 01752, Tel. 617-481-3700. Our software only works with this particular A/D board. Recently, Data Translation put out a similar card (without the D/A function which we don't use, and available for either the PC/AT or PS/2 computers) at a lower cost. However, we have not tried this new card.

Using A/D boards made by other companies are possible. However, this will require extensive redesign of the PC-Quake system and rewriting of our present data acquisition software. Because this will take many months to do and many more months to test, it is not practical for us to investigate using any other A/D boards.

(6) Signal Processing Board

We have tried a TMS32020 based Coprocessor Board and software from Symmetric Research. This board is designed for signal processing and is 10 to 20 times faster than a VAX/780 mini-computer. This board is optional, but you will need this board and its software if you plan to do digital filtering, spectral analysis, etc. They are available from Symmetric

Research, 15 Central Way, Suite #9, Kirkland, WA 98033, Tel. 206-828-6560.

(7) Printer, Mouse, and Surge Protector

We use a dot matrix printer as a poor-man's hard copy unit. In practice, we have used an IBM Proprinter II with printer buffer and cable. Our software for printing graphics off the monitor screen requires a 100% IBM or Epson compatible printer.

Most of the off-line processing and analysis software (please note that most of them are written by our outside collaborators and are not included here with this open-file report) requires a mouse as a pointing device. We have used a Microsoft serial mouse. Avoid using a bus mouse because it may conflict with other adapter cards in your system.

Because the AC electric power may fluctuate, we recommend using a high-quality surge protector to protect your computer equipment. If you have electric power failure problems, then use an uninterruptible power system (UPS). For field work where there is no AC electric power, we have used an UPS made by Best Power Technology (P. O. Box 280, Necedah, WI 54646, Tel. 800-356-5794). With four large batteries, we have operated our PC/AT and associated equipment for several hours in the field.

(8) Removable Mass Storage

We have tried the Bernoulli box, a 20 MB removable disk drive by Iomega Corp., 1821 West 4000 South, Roy, UT 84067, Tel.

801-778-3000. We have also used a WORM drive made by IBM (Model 3363) which is a write-once-read-many removeable optical cartridge system and has a 200 MB capacity.

The "best" mass storage for transferring data (from the on-line unit to the off-line unit) at present appears to be a removable hard disk (for example, the Passport 40 MB removable hard disk made by Plus Development Corp., 1778 McCarthy Blvd., Milpitas, CA 95035, Tel. 408-434-6900 or 800-826-8022). However, we do not have the fund to try it.

The "best" mass storage for archiving data at present appears to be a WORM drive. We have used an IBM 3363 WORM drive. It behaves just like a hard disk so you can organize your data in directories. It is faster than any other alternatives. For example, you can copy 20 MB worth of files from the AT hard disk to it in about 8 minutes.

The removable mass storage is optional. If funds are limited, you may copy files from the on-line system to floppy diskettes using the DOS copy command, or use FAST BACK (by Fifth Generation Systems) or similar programs to backup files from a hard disk to floppy diskettes. We found that the Bernoulli box and the IBM WORM drive are too slow to keep up in real-time operation. Therefore, we can not use them at present for normal data acquisition. Consequently, you have to stop the real-time data acquisition for about several minutes each day (depending on seismicity) to copy the data from the hard disk to the removable media. Because the Passport removable hard disk can be removed in a few seconds and was highly recommended by the PC Magazine (vol 7, no. 15, 9/13/88), we think it may worth a try.

(9) Operating System Software

We are using IBM DOS 3.3 Operating System which can be bought from many computer stores. For some PC/AT compatibles, you may have to use MS DOS 3.3 to set up your system and format the hard disk. After your system is bootable from the hard disk, you may transfer IBM DOS 3.3 to it.

Because the hard disk becomes fragmented after a few weeks' use, you need to de-fragment it once a month or so. Otherwise, access to the hard disk becomes slower and slower. For this function, we have used PCTOOLS by Central Point Software, Inc. (15220 N.W. Greenbrier Parkway #200, Beaverton, OR 97006, Tel. 503-690-8090). You can also use it for disk management and file backup, and it costs about $60.

(10) Required Application Software

The required application software in executable form (except those we can not distribute: Data Translation's ATLAB, Hercules' HGC.COM, and DOS 3.3 operating system) is available on a standard 5.25 inch floppy diskette (Disk #1 of two diskettes that accompanying this report). The on-line program is called MDETECT. Please note that it is Version 2, and still contains many "bugs". Two off-line programs are also included: XPLAY (Version 2), and XPLAYEGA (Version 2). There are several additional off-line programs for picking arrival times, windowing and filter seismic traces, and computing spectra and coda Q attenuation. They are not distributed here because they were written by our outside collaborator. However, these off-line programs will be included in a forthcoming publication (Lee, 1989).

(11) <u>Other Software</u>

We assume that you will be using a Hercules Graphics card so that you will have access to the HGC.COM program (and others) that come with the Hercules card. This program is called to blank out the monitor screen after a short time without keyboard input. This is used to preserve your monitor display so that it is not lighted up unless you press a key. HGC.COM is also used for screen dump to a dot-matrix printer, and is especially useful if your system crashed and you wish to print the error messages and the last display of seismic traces. Your system may crash for a variety of reasons. Most of the time you can perform a warm boot, but sometimes a cold boot is necessary.

For setting up input data files, you will also need a text editor. Although you can use EDLIN (included in the PC-DOS operating system), we have used KEDIT by Mansfield Software for ease of text editing. To manage disk files on a hard disk, we have used XTREE by Executive Systems, Inc.

If you wish to customize your own software and develop new programs, then you will need the compilers by Microsoft (C, Fortran, and Macro Assembler), source code from Lee (1989), and other commercially available software specified in Lee (1989).

4. APPROXIMATE COST OF A SYSTEM

We recommend at least two identical systems so that one serves as on-line, and one serves as off-line. The off-line system can backup the on-line system if necessary. At present, we have NOT solved the problem of writing the data directly to removable mass storage on a real-time basis. The problem is that the removable mass storage devices that we tried (Bernoulli Box and IBM 3363 WORM drive) can not keep up with the current on-line program in saving the digital data. Based on the specifications of the removable hard disk by Plus Development, Inc., one should not have any difficulty using it in place of the PC/AT hard disk because it is faster in both access time and data transfer rate.

If you have two systems, you can always start the second one as the on-line system, and make the previous on-line system serve as the off-line system. Once it is off-line, you have plenty of time to analyze your data and archive the relevant data on removable storage media. Alternatively, our on-line program (MDETECT) does allow stopping the real-time data acquisition automatically at a preset time each day for transferring data to removable mass storage, and restarting the real-time data acquisition afterwards.

The cost of the PC-Quake system depends heavily on what options you choose and where you buy them. In general, a minimum system unit can be assembled for as little as $5,000, but a full-featured system unit may cost up to $10,000. For budgeting purposes, we recommend approximately $25,000 for a two-unit system plus some money (i.e., $5,000) for system integration and software customization needed for your applications. Here is the approximate breakdown for one system unit:

(1) A high-quality, 100% IBM compatible PC/AT (e.g. AST 286 Premium PC or COMPAQ Deskpro 286 PC), with 40 MB hard disk, 1.2 MB floppy drive, 2 MB RAM, 80287 Math Coprocessor, 1 serial port, 1 parallel port, AST 3g EGA or equivalent card, NEC Multisync or equivalent color monitor, & keyboard..$4.0 K

(2) Hercules Graphics Plus card & monochrome monitor ...... 0.3 K

(3) Data Translation DT2821, Terminal Panel & Software .... 2.0 K

(4) Symmetric Research Signal Processing Card & Software .. 1.3 K

(5) A removable hard disk drive plus 2 removable disks .... 1.5 K

(6) A dot-matrix printer, and printer cable .... 0.5 K

(7) Microsoft serial mouse and surge protector .... 0.2 K

(8) IBM PC-DOS, and PCTOOLS software .... 0.2 K

Total: $ 10.0 K

For the off-line unit, you may wish to buy an IBM 3363 WORM drive ($2.2K) for archiving waveform data. You can also get by with a single monitor system. In this case, you save about $800 for the EGA adapter and monitor. Because (4) and (5) are optional on both the on-line and off-line units, you can save an additional $2.8K. Therefore, a minimum monochrome system costs about $5,500. If you uses a low-cost PC/AT clone with a compatible Hercules card, the rock bottom cost is about $4,000. All the above costs do not include any sale tax or shipping charges.

5. PC-QUAKE VERSION 2 SOFTWARE

The PC-Quake Version 2 software is contained in two standard 5.25 inch floppy diskettes (double side, double density, 360 KB). The first diskette contains the executable and associated files. The second diskette contains the source code files written by us at the USGS and this Open-file Report. Contact: Books and Open-File Report Section, U. S. Geological Survey, Box 25425, Denver Federal Building, Denver, CO 80225 for ordering information.

Although these programs have been extensively tested, the U. S. Geological Survey cannot guarantee that it will give accurate results for all applications nor that it will work on all computer systems. In fact, the hardware and additional software to run the on-line data acquisition and processing system software are very specific as given in Section 3 above. The USGS source code given in Diskette 2 are for illustrative purposes only. In order to compile the USGS source code into executable programs, several non-USGS source code and object modules are also required (See last paragraph of Section 3 (11) above).

The first diskette contains the following files:

(1) READ.ME -- An introduction file.

(2) CONFIG.SYS -- Either use it or add it to your own CONFIG.SYS.

(3) AUTOEXEC.BAT -- Either use it or add it to your own AUTOEXEC.BAT.

(4) SAMPLE.INP -- An example showing you how to set up an input file required by MDETECT.

(5) SAMPLE.STA -- An example showing you how to set up a station file required by HYPO20 within the MDETECT program for earthquake location.

(6) MDETECT.EXE -- Executable code for doing the on-line data acquisition and processing. It contains codes contributed by non-USGS scientists and provided here through their courtesy on an experimental basis.

(7) XPLAY.EXE -- Executable code for playing back the digitized waveform data; this version is for the Hercules (or compatible) Graphics Card connected to a monochrome monitor.

(8) XPLAYEGA.EXE -- Same as (7), except it is for the EGA (or compatible card) connected to an EGA color monitor.

The second diskette contains the following files.

(1) READ.ME -- An introduction file.

(2) MDETECT.SRC -- Source code written by USGS staff for the MDETECT program. It is for illustrative purpose only.

(3) XPLAY.SRC -- Source code written by USGS staff for the XPLAY and XPLAYEGA programs. It is for illustrative purpose only.

(4) PCQUAKE.RPT -- A copy of this Open-file Report in ASCII format using the Volkswriter word processor.

We assume that you have already installed IBM DOS 3.3 operating system and that COMMAND.COM is in the root directory. We recommend that you put (1) and (2) in your root directory. Set up a sub-directory called \MDETECT and copies (3) through (8) into it. You also need to set up two other sub-directories from the root as follows:

(1) \Hercules -- Copy HGC.COM from the diskette accompanied with your Hercules Graphics Card. (Please note we can NOT distribute this program).

(2) \ATLAB -- Copy ATLAB.SYS from the ATLAB software package sold by Data Translation, Inc. (Again, we can NOT provide it).

6. LIMITATIONS OF THE PC-QUAKE SYSTEM

The PC-Quake system can do the following:

(1) Digitizing up to 16 seismic signals (or 15 seismic signals plus 1 time signal) at up to 100 samples/second in standard network monitoring mode (i.e., trigger on event, automatically pick P-arrivals and locate event, and save up to about 120 seconds of digitized data per event). A larger event may appear as several event files. The amount of data to be saved before or after an event can be set by you. If you just wish to digitize and save the data (e.g., to record an explosion), you can run the program on a "free run" mode. In this case, you can digitize up to 500 samples/second per channel for 16 channels, or up to 1,000 samples/second per channel for 8 channels.

(2) The digitized data are displayed continuously in real-time with a delay of a few seconds. In normal operation, the monitor screen is refreshed every 5.12 sec.

(3) A log file displays what is happening on a dual monitor system and is also saved on the hard disk for later review.

Limitations of the present PC-Quake system are many:

(1) It is at present limited to 16 channels. We have demonstrated that the PC-Quake hardware is capable of digitizing 64 channels if an external multiplex board is built and the A/D board is modified. However, there is NO software support for it.

(2) PC-Quake Version 2 software still has some "bugs", and there is no support from the USGS. Result from California indicate that if the analog seismic signals are "clean", then there is no problem detecting earthquakes of magnitude 1 or larger. However, there will be many falsely triggered events if the analog signals are noisy. Obviously, users must fine-tune the input parameters for their particular networks. The automatic picking of P-arrivals depends critically on analog signal conditions. Obviously, the automatic event location is no better than the quality of the P-picks and the station distribution with respect to the hypocenter.

(3) We noticed several types of system crashes. If you use a low-cost PC/AT compatible, the computer may be iffy and crashes often, as with a low-cost PC/AT that we tested. If the on-line program falls behind (too many consecutive events, too many noisy signals, fragmented hard disk, etc.) then the data acquisition buffers may overflow and causes the system to crash. This is why we recommend a high-quality PC/AT, 2 MB RAM for data buffers, and optimizing your hard disk every week or so with the PCTOOLS software. The location program used (modified HYPO71PC) also crashes occasionally when a low-cost PC/AT was used. We are not sure of the cause(s) -- it seems that the math coprocessor chip occasionally acts up and/or there are some unknown program bugs.

(4) The present PC-Quake system does NOT keep accurate absolute time. The PC/AT clock is used for time stamping when you first start the MDETECT program, and it may drift several seconds a

day. We also keep time by counting the digitizations performed by the A/D board, and it is good to about 2 seconds per day. Although a time trace is also digitized, the present Version 2 software does NOT use it. The relative times of digitized data are good to a few milliseconds because channels are digitized in sequence every 0.01 sec in normal operation. However, if you need absolute time, you will need a satellite clock to synchronize your PC/AT clock frequently, and write additional software to utilize the digitized time signal for time corrections.

(5) The automatic picking of P-arrivals and the earthquake location parts of the program need refinements for acceptable performance. At present, the quality of the results is still too poor, and should be used only as a rough guide. In other words, you must verify the P-picks and relocate the event to make sure that they are correct after transferring the data to the off-line system.

In conclusion, the PC-Quake system is a poor-man's solution to the seismic data acquisition and processing of a small telemetered analog seismic network. If properly completed, it may be the most cost-effective way to bring many local networks into the "digital world". Unfortunately, funds are not available to adequately complete this system within the USGS. This is one reason our current work is being released "as is". We also working with outside collaborators to complete a revised version and a user manual to be published as Lee (1989).

Unlike most other computerized seismic systems, the PC-Quake system was implemented in less than one year. The authors spent a total of about one man-year in developing and testing the system. The authors wrote only about 2,000 lines of new code. Such a quick implementation of PC-Quake system was possible because (1) the authors benefit from 20 years of research on automatic seismic data processing by USGS and outside seismologists, (2) the PC technology and commercially available software, and (3) contributions from our outside collaborators.

At present, we and our collaborators are operating 10 PC-Quake systems in seven sites: (1) Yakutat, Alaska (USGS), (2) Spokan, Washington (U. S. Bureau of Mines), (3) Moscow, Idaho (University of Idaho), (4) Vancouver, Washington (USGS), (5) Menlo Park, California (USGS), (6) Mexico City, Mexico (National University of Mexico), and (7) Scot Base, Antarctica (Victoria University). Several more PC-Quake systems are scheduled to come on-line soon: Stanford University, Jordan Seismic Network, Jordan, and National University of Ecuador.

Finally, we wish to urge interested seismologists to pool their development resources together to complete an adequate PC-based seismic system for all.

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REFERENCES

Allen, R. V., 1978. Automatic earthquake recognition and timing from single traces, Bull. Seism. Soc. Amer., v. 68, p. 1521-1532.

Ellis, J. O., 1988. Expanding the input multiplexor for the Data Translation, Inc. model DT2821 Analog to Digital Converter, U. S. Geol. Surv. Open-file Report, in preparation.

Lee, W. H. K. (Editor), 1989. Software package for data acquisition, processing, and analysis of a local seismic network, IASPEI Software Library, Vol. 1, Seismological Society of America, El Cerrito, in preparation.

Lee, W. H. K., and S. W. Stewart, 1981. Principles and Applications of Microearthquake Networks, Academic Press, New York, 293 pp.

Lee, W. H. K., and C. M. Valdes, 1985. HYPO71PC: A personal computer version of the HYPO71 earthquake location program, U. S. Geol. Surv. Open-file Report 85-749, 43 pp.

Lee, W. H. K., D. M. Tottingham, and J. O. Ellis, 1988. A low-cost PC-based seismic data acquisition and processing system (Abstract), EOS, v. 69, p. 1321.