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A MICROCOMPUTER-BASED TREE-RING MEASURING SYSTEM

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ABSTRACT

A brief discussion is presented on a new measuring system based on an APPLE microcomputer. Aspects of both hardware and software are considered, with emphasis on the software that provides operator interaction. The system uses diskettes for data storage and completely eliminates both paper tape and key punch cards from the measuring process.

INTRODUCTION

In 1964, the Laboratory of Tree-Ring Research developed its first automatic device to record ring widths. This "measuring machine" replaced a Swedish manual ADDO-X which in turn had been a major advancement in data capture. This machine was designed and constructed by the Fred C. Henson Co. of California and was the product of development begun in 1939. The 1964 device consisted of two parts. First, a hand operated precision 1 mm pitch lead screw was employed to drive a mechanical stage and tree-ring sample under a fixed stereoscopic microscope equipped with a crosshair. The lineal displacement of each ring was encoded to a resolution of 0.01 mm by an electromechanical digitizing switch fitted to one end of the lead screw. Second, a custom "black box" scanned the digitizing switch, entered the data on an adding machine, caused the adding machine to print the increment on paper tape and to label each decade with its correct calendrical year. Later, punched paper tape output was added. This system was in operation for approximately five years.

In 1970, the need for additional measuring capability led the Laboratory to locally duplicate the Henson "black box" with updated electronics. An additional precision lead screw was acquired from Henson and both lead screws were fitted with optical incremental shaft encoders. The intention was to capture data on magnetic tape as well as on paper tape, producing a major improvement in the system. Unfortunately, this system proved to be unreliable electronically and mechanically and was in operation, off and on, for only a few years.

The continuing need for additional, reliable measuring devices was satisfied in 1972 by a new concept pioneered again by the Fred C. Henson Co. Due in part to projected costs of precision lead screws, this new system was based on a simpler measuring device operating directly on lineal displacement rather than encoded rotary motion. As a consequence, a newly-designed measuring stage was equipped with a dial indicator that was convertible to use with a standard lineal displacement transducer. The transducer was powered by a separate supply manufactured and maintained by a national firm. The output voltage from the transducer was directed to a "stock, off-the-shelf" measuring system which included visual digital display, a voltmeter to measure transducer output, and a conversion unit that supplied binary coded decimal

(BCD) output to a digital impact or thermal printer. This system had the advantages of good reliability and relatively low acquisition and operating costs. It had, also, two nagging disadvantages. One, the transducer required daily — or more frequent — calibration due to its sensitivity to both current change and physical movement. Second, the paper tape output consisted of columnar measurements without identification, calendar years, or other pertinent documentation. These were all entered by hand.

The development of the microcomputer-based measuring system discussed in this paper was precipitated by two events. First, a 1972-vintage measuring system suffered electronic failure after eight years of constant use and the cost of repair was estimated at a figure that appeared noneconomic. Second, an investigation of microcomputers suggested that many were cost competitive with the less sophisticated voltmeter system and could be interfaced to the encoding devices with a minimum of hardware. After investigation of cost, interfacing ease, software and support, an APPLE II Plus microcomputer was chosen as the basis of the system.

THE SYSTEM

Encoder

Since the Laboratory already possessed four measuring stages with precision lead screws (two custom Henson stages and two ADDO-X stages), optical incremental shaft encoders were fitted to all four stages by the University machine shop. The shaft encoders have a resolution of 0.002 mm. They are bidirectional and require + 5 volts, direct-current (vdc) input. They provide a square wave, TTL-compatible, output. The external connector is a standard 7-pin type mounted at the end of the encoder. In this case, only four pins were used; one for + 5 vdc, one for ground, one for incremental direction sensing, and one for reverse direction sensing. This part of the system may probably be used with nonprecision lead screws by replacing the transducer with a lineal glass encoder which has input/output characteristics identical to the shaft encoders under discussion. The Fred C. Henson Co. has developed this alternative and is offering their present laboratory model with the lineal glass encoder.

The advantages of the shaft encoder over a transducer lie in the lack of need to calibrate, in far superior immunity from dust or, in our case, charcoal bits, and in its lack of susceptability to inadvertent measurements due to physical motion. The cost of either type of encoding device is identical. In addition, the shaft encoder draws power directly from the APPLE and does not, therefore, require a separate power supply.

Interface

The connector on the shaft encoder is interfaced to the "game" port of the APPLE. This game port is a 16-pin DIP socket that provides, among other unused functions, + 5 vdc, ground, and three one-bit, TTL inputs. Two of the latter connect the two-channel output of the shaft encoder, while the third is used for a hand-held push button that initiates the measuring cycle and zeros the accumulator to receive another measurement. Wire-to-wire interfacing is accomplished using a standard 6-screw terminal strip mounted in a box. A 4-wire cable leads from the shaft encoder to the terminal strip, as does a 2-wire cable from the push button. One end of a 16-pin ribbon cable is inserted in the APPLE game port with the other end cut and stripped for attachment to the proper terminals. Thus the entire physical interfacing is extremely simple and requires no hardware modification of the APPLE.

The APPLE Microcomputer

The hardware used for the system includes an APPLE II Plus microcomputer with resident APPLESOFT language. This language is APPLE's version of MICROSOFT floating-point BASIC. The computer is configured with 48K of random-access memory (RAM), a 5" floppy disk drive, and a 9" black and white video monitor. Both the disk drive and the monitor sit on the APPLE so that the total space occupied by the system is only approximately 15" by 18". We place the system on a wheeled, 34" high projection table with the terminal strip box fastened to the table. This allows the operator to place the video screen at a convenient distance and angle for viewing, as well as to avoid placing both electronics and samples on the same surface.

The APPLE II Plus has an autostart feature that automatically loads and runs a program from disk when the APPLE is turned on. This allows for simple system startup. A possible improvement that would increase RAM memory and avoid the use of disks for the programs would be to place the measuring programs in read-only memory (ROM) on an I/O board. Once done, however, program changes would be precluded.

Software

The software developed for the measuring system was accomplished in three linked programs. The first, a standard "greeting" program, boots the disk operating system using the autostart feature. The greeting program automatically loads the two operating programs that will be discussed in greater detail.

The program titled PULSE COUNTER is written in assembly language and resides, after loading, between $0300 and $0396 in memory. This program monitors inputs from the shaft encoder, the operator control switch, and the computer keyboard. When a pulse train appears at the port, the program determines in which direction it should count and accumulates the count. When the operator signals the end of a measurement, the program stores the current count in a location used by both programs. It then passes control to the main program.

The assembly language program uses the instruction set of the 6502 microprocessor on which the APPLE is based, so PULSE COUNTER can not be transported to non-6502 based microcomputers. Assembly language, however, has the advantages of using very little space in RAM and of swift execution, which is important in the measuring process. The program is so compact, in fact, that it is placed in a memory area not usually available for programs, thus allowing more free RAM for data.

The main and visible program is called, appropriately enough, MEASURE. This is a menu-driven program written in BASIC and is approximately 6K in length. After loading this program, the APPLE has about 30K free RAM or sufficient memory to handle a core of nearly 10,000 years length.

The menu provides seven options: measure (1), review (2), put on disk (3), get from disk (4), edit (5), plot (6), and quit (7). Most of the error-trapping routines that are built into the program return to this menu. Selection from the menu is by single keystroke.

The measure option (1) first asks for the operator's name, the identification number of the sample to be measured (at present a 6 character alphanumeric code), the date, and the beginning year of the sample. The beginning year may be either a calendrical A.D. year or a positive arbitrary year such as would allow the end date to be less than 10,000. The program then queries the operator about the correctness of the input and allows a restart. If the operator agrees (by single keystroke) with this input, the program then sets up the measuring display for the monitor. On the right half of the screen, instructions are written to press the trigger to record a ring (or a zero) and to press the "9" key to end measuring and return to menu. The left half of the screen displays two matched columns with the years in one column and the actual measurements (in integer mm) in the other. As the screen fills, these columns scroll up so that a maximum of 20 measurements are displayed at any given time.

As the trigger is pushed, the program calls the assembly language program, gets the values of the counts from the shaft encoder, and converts them to integer millimeters. A single beep from the APPLE's speaker is also sounded. There are also subroutines to right justify the measurements in the column and to disallow a negative measurement.

When measurement is completed, usually at the end of a sample, the "9" key is pressed on the keyboard. This action terminates the measure option, adds a final year with the value of 999 as an end of file mark (Graybill 1979), and returns the operator to the menu. Thus, under this system, the maximum measurement possible is 9.98 mm. But this could easily be changed however if the end of file mark were changed.

The review option (2) returns the measurements and year labels to the screen in sets of 15 years from the beginning. A single keystroke displays the next set and a "9" key provides an escape and return to the menu. This option is used primarily to scan the data after completing a core, to check beginning and ending years, and to look at the placement of critical rings.

The two options (3 and 4) that deal with the disk are nearly self explanatory. Both ask for the core identification number of interest and then either write the file onto the disk or return it from the disk to memory. Files are treated as sequential text files with the usual commands of the disk operating system. A core may be returned from disk, edited, and reSAVEd on disk with all corrections intact.

The edit option (5) is similar to review in tha the measurements with their year labels are again displayed in 15-year groups beginning at the earliest year. However, a number of single keystroke commands are added and displayed at the bottom of the screen. These commands allow the operator to Insert a ring that has been missed, to Change the value of a ring by entering the value on the keyboard, to Remeasure a ring changing its value by means of actual measurement, to Delete an extra ring or a double that was measured as a ring, and to Quit and return to the menu. In most cases, after the command is entered on the keyboard, the screen asks the operator which year he wishes to alter, waits for the operator's input, and make the change. To delete, a further safeguard is afforded by displaying the value of the ring to be deleted and asking for verification. In both insert and delete the data set is adjusted automatically and the appropriate years are relabeled. A combination of commands has proved to handle the usual errors committed by measuring operators.

Finally, the plot option (6) provides a *simulation* of a skeleton plot to visually display placement of critical small rings in the measured series. Using low resolution graphics, the data set is divided into group of 40 years or somewhat less (dependent on the total length), the average ring value for each set is calculated and displayed in the traditional inverse relationship. Thus a zero ring has the greatest value which is a line length on the vertical scale approximately equal to the line length of 10 years on the horizontal scale. The displayed data set is limited to 40 due to the width of the display available in the APPLE's low resolution graphics mode.

Data Transmission

Another program has been developed to transmit ring-width data, via the telephone, to an interactive mainframe computer for subsequent data manipulation with programs RWLIST, INDEX, and SUMAC (Graybill 1979). The transmission program is structured to use a Micromodem II and is specifically configured to interface with a Digital Equipment Corp. System 10 mainframe computer. The software is menu-driven and provides options to transmit data or to print the data locally if the APPLE is interfaced to a line printer.

The primary concern in the design of the data transmission option was to keep operator interaction with the program at a minimum. This concern is justified by the amount of time involved in transmission of an entire tree-ring site (a minimum of 20 cores or "files"). An average southwestern US tree-ring site takes at least 60 minutes to transmit with the operator free to undertake other tasks while the program runs.

The system consists of a BASIC program in the APPLE and a FORTRAN receiving program on the DEC-10. After first running the program, the operator is asked to enter the file name (known as a job number) which identifies the DEC-10 disk file used. The operator then enters all the file names (core ID numbers) to be transmitted. The screen displays a list of these core numbers and provides an opportunity to add, delete, or correct any misentry. After acceptance of the core IDs by the operator, the BASIC program enters a loop that automatically dials the telephone and continues until a carrier signal is established. The operator then performs normal log-on procedure and is returned to the BASIC program. The data transmission program then issues a command to the DEC-10 to execute the FORTRAN receiving program and sends the file name (job number) to identify the disk file.

Each core (or other sample) is then individually read from the diskette, where it was stored by the MEASURE program and transmitted to the receiving program. For each core, a sum and a sum of squares is calculated by both the APPLE and the DEC-10. On completion of transmission, these sums are sent back from the DEC-10 to the APPLE where they are compared. If the results are not zero (with allowance for rounding errors), the entire file (one core) is retransmitted. Since this procedure produces duplicate data on the disk file, an error message containing the duplicated line numbers is produced on the line printer. The duplication is deleted before running RWLIST.

This procedure is repeated automatically until all files have been transmitted. The program then logs the user off the DEC-10 and prints a hardcopy list of the individual core ID numbers transmitted. Finally, the program returns to the menu for more transmission, hardcopy printing of data, or exit.

The print option provides a hardcopy listing of each core. In terms of operator interaction, this option is similar to data transmission and, in fact, shares subroutines. The operator enters a list of the core IDs to be printed and is given the opportunity to edit this list. The cores are loaded, one at a time, and printed. The format of this listing is similar to RWLIST in that each line contains the core ID number, decade, and ten (or less) values.

CONCLUSION

The measuring system has been operational for approximately four months and has received extensive testing through use. Operators accustomed to older systems have found conversion extremely easy. It is estimated that measuring time has been at least halved through the elimination of paper tape output. In addition, the programs provide for more sophisticated screening of data than previous systems. This insures greater accuracy of data when released by the operator for transmission and manipulation.

Data transmission has been tested along with the measuring system and has proven to be equally reliable and easy to use. Although transmission using a 300 baud telephone line is somewhat slow, the elimination of card punching and verifying has led to a dramatic overall increase in productivity. In addition, data storage on diskettes and magnetic tapes has replaced the need for card storage and handling.

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