TIMING SYSTEM DESIGN CONSIDERATIONS FOR A MOBILE ASTROLABE

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ABSTRACT

The Danjon Astrolabe at the Naval Observatory has been traditionally used to determine Universal Time and improve the systematic accuracy of star positions. During the past year, it has been used to determine latitude and longitude at remotely scattered sites for geodetic purposes. Operating this instrument away from the Observatory necessitated a mobile support and timing system rugged enough to operate dependably in ever changing, and sometimes harsh, environmental conditions.

This paper describes the performance of the astrolabe timing system, gives the basic engineering design considerations, and describes the equipment and instrumentation.

INTRODUCTION

In cooperation with the Defense Mapping Agency an evaluation study was made of astronomical observations acquired using a Danjon Astrolabe at reference points in the western United States extensively used in the past for astro-geodesy.

When the idea was conceived of improving the deflection of the vertical at specific locations with position determination by astronomical measurement and extending this accuracy to large geodetic nets, a high-precision observatory instrument was considered. The Danjon Astrolabe was selected for this work because its accuracy and mobility make it well suited for basic astro-geodetic work. The optical Danjon Astrolabe determines position to within one meter accuracy and requires a timing system that records time-of-day for timing events with 100 microsecond precision. It is an observatory instrument which can be transported and set up overnight.

The astrolabe had been previously used at the Naval Observatory on a regular basis for the determination of Universal Time (UT0) and for reducing the systematic errors in the positions of the stars observed. Like the Photographic Zenith Tube (PZT), the visually operated astrolabe is an efficient instrument for the simultaneous determination of time and latitude. Unlike the PZT, the astrolabe can observe a much larger subset of the so-called "fundamental stars" (i.e., stars for which accurate, precise and consistent positions and proper motions are available), thus yielding better coordinates in a relatively short time. This is important when moving from one place to another because a different subset of the fundamental star catalog is selected for each observing site.

Since the astrolabe would not be operating in an observatory environment, which is essentially a research laboratory environment, it was necessary to provide the astrolabe with rugged field peripheral support equipment which could survive under adverse temperature and weather conditions (e.g., snow, rain, electrical storms, poor and unreliable electrical power, blizzards, desert heat, etc.). The field equipment described herein includes a portable atomic frequency standard and clock, a "Datachron" chronometer interfaced by means of a Fairchild 4880 coupler unit to a HP9915A modular computer with both a built-in magnetic tape cartridge drive (Option 001) and a video, keyboard, and audio speaker interface (Option 002). An HP-IB Interface (HP Part No. 82937A) card was inserted into one of the three available I/O slots in the rear of the HP9915A. Additionally, an HP85 desktop computer with an HP82939 serial interface communications card and an Anderson-Jacobson Model AJ1234 (Mfr. code 2852) communications modem was used for editing and transmitting the recorded astrolabe data back to the Naval Observatory. A motor vehicle provided housing and transport for the above equipment; and, when the astrolabe was being transported to a new site, the same vehicle provided 12 VDC power to the portable atomic clock. At the observation sites, the motor vehicle also served as a field operations center and as a dressing room for the observers. While on site, external electrical 110 VAC 60 Hz power was provided by extension cables only to the motor vehicle. Electric power to all other instrumentation, including the portable atomic clock and the Danjon Astrolabe, was provided from a common distribution box in the motor vehicle.

OBSERVATIONS AND SYSTEM DESIGN

Basically, time-of-day data to 0.1 millisecond accuracy is acquired by the Danjon Astrolabe (Figure 1) by timing stellar images as the star, in its diurnal sidereal path, crosses the 30^{0} almucantar (a small spherical circle centered on the zenith and having a radius of 30^{0} of arc). Normally, three groups of stars are observed every night. Each group consists of about 30 stars with magnitudes between 3.0 and 6.5, whose almucantar transits are uniformly, or nearly so, distributed in azimuth among the four azimuth quadrants. By forming the time difference between the observed time-of-day of almucantar passage and the calculated time-of-day based upon the positions of the stars as found in a precision astrometric star catalog such as the FK4, it is possible to determine the observed zenith distances for each star at the time of its passage through the almucantar. By combining the observed zenith distances in the same manner that a marine sextant navigator combines intersecting LOP's (Lines of Position) to determine a position "fix", the astrolabe determines an astronomical "fix" and the associated astronomical latitude, longitude, and refraction correction are determined with high precision.

When a stellar almucantar passage is observed, a motor-driven micrometer carriage causes electrical contacts to open and close twelve times, thus causing 24 electrical signals to be generated and whose time-of-day occurrence must be recorded by a chronometer. During the observation interval, i.e., the time interval during which the electrical contact signals are being generated, the star may move as much as 312 seconds of arc in altitude. A speed reducer varies the speed with which the star is tracked in a manner proportional to the sine of the azimuth; and the observer needs only to make slight differential adjustments in the speed with which the star is tracked to maintain the optical null condition of the star images in the eyepiece. In this manner, the observer controls the occurrence of the contact timing signals. The observer has only two variables to reckon with: (1) the instant at which to begin the observing sequence, and (2) having started the observation, to differentially adjust the speed at which the timing contact signals occur so as to first achieve and then maintain the optical null condition of the star images in the telescope eyepiece.

The micrometer of the Danjon Astrolabe is based on standard Repsold transit micrometer techniques. At each micrometer position at which an electrical contact generates a signal, a linear micrometer reading in say tens of micrometers is recorded. The average time of all 24 timing contact signals then equals the time at which the micrometer was located at the average of the 24 linear micrometer readings. By also determining the linear micrometer reading for the position of the focal point of the Danjon Astrolabe objective lens, it is then possible, from a knowledge of the azimuth, to determine a correction to reduce the centroid of the 24 timing contact signals to the time corresponding to the null passage of the star's images through the focus of the Danjon telescope objective. It is necessary, in order to determine these corrections, to be able to record the time-of-day of each timing contact signal. It is also necessary to form the first differences of the times-of-day in order to set the basic driving motor speed, which is proportional to the latitude of the field site.

Thus, the field timing system for the astrolabe not only had to record timing pulses that arrived at separation intervals that could be as small as 0.3 seconds and no greater than 10.0 seconds, but also had to be able to form and display, on a TV monitor, the time of day and its first difference with the previous time of day. The TV monitor shown in Figures 2 and 3 could be used inside the vehicle or outdoors next to the Danjon Astrolabe.

The transfer and readout capability, including the necessary programming, for field operations of the astrolabe was designed by the Time Service Precise Time and Time Interval (PTTI) Branch of the Naval Observatory. This capability (illustrated in Figures 2, 3 and 4) consists of a HP9915A computer, which served as a control and recording unit, an electronic "Datachron" chronometer, and a portable cesium atomic clock. Use of an atomic clock might be thought of as "overkill", but in field experience, the ability to avoid propagation errors and constant worries over crystal oscillator behavior, proved to be invaluable.

The micrometer contact electrical signals are sent from the astrolabe to a "Datachron", a chronometer built at the Naval Observatory. The Datachron operates off the 5 MHz signal from the portable cesium clock, which also maintains the basic field time of day for the system. The Datachron is manually synchronized with the cesium clock and there are circuits which check for synchronization faults between the cesium and the Datachron. The portable cesium clock operates off an HP K02 portable power supply continuously. The HP K02 is operated mostly from an external power source or, during periods when the vehicle carrying the instrumentation is in motion, off of the vehicle battery. A special heavy duty alternator was installed to insure that the vehicle had enough power to operate both day and night without discharging the vehicle battery. The vehicle cesium clock was always kept within 10 microseconds of the U.S. Naval Observatory Master Clock, UTC(USNO MC) by means of portable clock visits and by visits from nearby laboratory clocks with known traceability to the USNO MC.

The contact signals from the astrolabe are conditioned by a low pass filter, an optical isolator, and a one-shot trigger in order to avoid jagged contact noise and transient oscillations. The conditioned signal causes the Datachron to momentarily lock into a register, the current time of day. The 12 digit (hours, minutes, seconds, and six fraction of a second digits) time of day locked into the Datachron is then transferred to the Fairchild 4880 coupler. The Fairchild coupler next initiates a data transfer of the time of day over a standard IEEE-488 (HPIB) interface to the HP9915A computer. The Fairchild 4880 instrument coupler converts the Datachron high speed parallel data output into the standard IEEE-488 (HPIB) interface format. This conversion of the Datachron electrical wiring and timing interface to the IEEE-488 (HPIB) standard interface simplified the connection between the Datachron and the HP9915A computer. The transfers from the Datachron to the HP9915A are high speed; and any need for stacked data buffering of closely spaced timing signals is eliminated.

The HP9915A has a 16K byte memory. It can be expanded to 32K bytes maximum. Of the 16K bytes, approximately 2.5K bytes are used by manufacturer software, including the interface routines. The language in which the programming was written is BASIC. The application program uses 2.5K bytes and was burned into EPROM memory to avoid problems that may arise when programs have to be field loaded from magnetic cartridges under severe temperature conditions and the harsher electrical power environment encountered in the field. The EPROM program is listed, along with a running commentary in Appendix A. The running commentary includes a description of the IEEE-488 control and data messages used across the HPIB bus. The control message sequences implemented over the HPIB bus were carefully designed to allow high speed transfer of the Datachron TOD data to the HP 9915A.

Whenever the timing signals (or "ticks") from the astrolabe stop for more than 10 seconds, the HP9915A writes the timing data (in the form of an array containing up to 30 times-of-events) onto a magnetic tape cartridge. The 10 second pause in the signals from the astrolabe is interpreted by the HP9915A BASIC program as indicating that observations for a particular star are complete and that the time-of-event data may now be written to the magnetic tape cartridge. While the HP9915A was writing the time-of-event data for a star on the magnetic tape cartridge, a pair of audio beeps, the first at a high tone, the second at a lower tone, were issued to the observer at the Danjon Astrolabe. After the time-of-event data had been recorded and the HP9915A system enabled to again accept astrolabe timing signals, another pair of audio beeps, the first beep at a low tone, the second at a higher tone, was issued to the observer to let him know that the system was now ready to accept timing signals for the next star.

Normally, only 24 time ticks are recorded per star. Because temperature and humidity changes, contact bounce, and contact wear can cause more or less than 24 ticks, a maximum of 30 ticks may be recorded for each star observed. As many as 90 stars were observed each night and recorded on the magnetic cartridge. At the end of the night, the time-of-event data file on the magnetic tape cartridge was "closed" by pressing a programmer defined "END" button and the cartridge removed.

At the hotel or other convenient location the timing data on the cartridge was then combined with hand recorded environmental and instrumental data, observer comments, and other messages. This was accomplished using an HP85 computer. The HP85 computer was furnished with an Anderson-Jacobson 1200 baud telephone modem. By dialing the Naval Observatory HP1000 computer over the switched public telephone net from motel rooms and government phones, the data on the tape cartridge was transfered daily to the Naval Observatory. The data was then transfered from the Observatory HP1000 system to the IBM Series 1 system where preliminary editing of the data was done. Then the data was transfered to the Observatory mainframe IBM 4341 computer either by a RJE link or by magnetic tape. The final reductions and analysis of the data were done on the IBM 4341; and, for each group of stars, the resulting latitudes and longitudes were obtained daily. This near real time transfer and analysis of the data prevented serious problems from going undiscovered; and it may be stated that this procedure is to be greatly recommended because otherwise there is a high probability (higher than otherwise might be expected) that long intervals of measurements might be made which are subsequently found to be useless because of the invalidity or absence of a critical datum or measured quantity.

Occasionally modem data transfers were interrupted (usually by the HP1000 because it was busy and had to attend to other matters) and the data had to be retransmitted. Sometimes the data arrived garbled (this was rare, but it did happen). Problems with data transmission as such were rare. The doubling of the measurement and transmission of both the measurement and its doubled value served as a check on the accuracy of the transmitted data. Most problems encountered with the system were associated with the HP1000 being busy or transmitting strange messages. As there were known reliability problems with the HP1000 during this time, such behavior is not unanticipated. Fortunately the problems with the HP1000 were not so severe that data transfer was disrupted in ways which would have endangered field operations.

SOFTWARE DESIGN

The software for this system, shown in Figure 5, consists of three programs, one for automatic data collection of astrolabe timing signals, the second for manual entry of observer recorded data onto the magnetic tape cartridge, and the third for transfer of the data over the public switched telephone system to the Naval Observatory. The program in the HP9915A for automatic capture of the astrolabe timing signals operates in three modes.

The first mode is the star observation mode. In this mode the HP9915A collects the times-of-event for the astrolabe timing signals, insures that the time-of-event is for a stellar observation (it is possible for the observer to cause isolated timing signals from the astrolabe accidently; these isolated timing signals from the astrolabe are identified by the HP9915A and ignored; the magnetic tape cartridge is thus not cluttered up with accidental sets of timing signals of no interest), and stores the data on the magnetic tape cartridge when the observation for each star is complete. If the data being collected by the HP9915A does not meet the criterion (12 or more time-of-events must have been received) used to determine if the time-of-event data is from a star observation, then, as already stated, in this mode of operation the time-of-event data is merely discarded.

The second mode is used to calibrate the astrolabe after it is installed at a new observation site. The time-of-event data is collected by the HP9915A, a calculation to form the first difference between the time-of-event for the current event and the previous event performed, and then both the time-of-event and its first difference are displayed on a TV monitor. This information is used by the observer at the Danjon Astrolabe to set the astrolabe motor speed. The main BASIC program is structured so that the observer can put the HP9915A into this "calibration" mode at any time. Mode selection is performed by the observer by pressing a button on the front face of the HP9915A computer.

The third mode, the fast TICK mode, is used to determine certain telescopic instrumental corrections related to the Danjon Astrolabe micrometer carriage (i.e., Vm corrections). In this mode, which is entered by pressing the TICK button on the HP9915A, the astrolabe timing signals are merely beeped back to the observer as he reads the micrometer carriage linear readings at which each timing signal is generated. No times-of-event are recorded on the magnetic cartridge. These micrometer readings allow the centroid of the timing signals to be corrected to the time at which the astrolabe stellar images coincided in the focal plane of the objective of the astrolabe.

The second program, the manual data entry program for the HP85 computer, allows the observer to manually enter all necessary information such as number of stars observed, ambient temperatures, barometric pressures, wire corrections, 2 or 4 ticks per revolution, observing conditions, and comments concerning each observation. The same magnetic tape cartridge used by the HP9915A to record the time of event data for each star is used by the HP85 and this program. A second file, created by the HP9915A when the observer set up for the evening's observing program but left empty, is opened for the manual entry of the observer's information, the necessary data entries made, and then again closed. A later version of this program allowed a certain amount of manual data entry in a "question and answer format."

The third program, the data transfer program, is then executed. This program requests the operator/observer to dial the telephone number of the HP1000 computer at the Observatory, provides the telephone numbers needed by displaying them on a small video screen, and then, when the HP1000 answering tone is heard, to place the telephone into the cradle of the 1200 baud Anderson-Jacobson modem. A special high quality transmission microphone (a Novation "Super Mike") was used in place of the standard carbon telephone microphone. This improved the quality of the data communications bit error rate by increasing the signal to noise ratio. The communication link over the public switched telephone is carried out in 7-bit ASCII, 1 start bit, 1 stop bit, and in even parity. Once the telephone connection has been established, a conversational protocol is executed by the talking computers (i.e. the HP85 and the HP1000). The HP85 first identifies itself to the HP1000 and requests access to the pre-established astrolabe data file on the HP1000 system. The HP1000 opens the astrolabe data files and then informs the HP85 that it may proceed to send data to the HP1000, which will direct all subsequent received data into the HP1000's pre-established astrolabe data file.

The HP85 first opens the manual information file on the magnetic tape cartridge and transfers the entire file to the HP1000; then, without breaking the telephone link, it opens the time-of-event file on the cartridge and transfers this file, in its entirety, to the HP1000. Finally, the HP85 requests the HP1000 to send to the HP85 a file containing messages and other information which the astronomers at the Observatory wish to send to the observer. Typical of such messages are queries concerning problems with pathological time-of-event data, missing data, and administrative messages. All messages sent from the HP1000 to the HP85 are displayed on the CRT of the HP85. The observer may thus evaluate the quality of the telephone connection. The observer may also print out these messages.

To prevent errors and to check the validity of the data transmission, both the time of event and twice the value of the time of event are transmitted to the Observatory by the HP85. This allowed another check to be performed upon the data as received at the Observatory from the field observer. In some cases, retransmission was deemed necessary because the error rate was too high.

When all data transfer operations were complete, the data files on both computers were closed and the computers send each other "GOODBY" and hang up.

SUMMARY

This project lasted about 11 months (August 1982 ---June 1983) and used three observers on a rotating basis. The building, testing, and installation of the data acquisition and timing system required no more than 6 weeks preparation. The timing system used provided considerably more numerical precision than actually needed because of other limitations (errors in star catalog positions); but the reliability was outstanding for field operations and was proven under severe weather conditions (blizzard, desert heat, electrical storms, driving rain and flash flood conditions). Uncertainties in star positions mean that star transits need be timed only with an error not to exceed a millisecond in the time of day. But time errors must not be systematic and they must not be allowed to creep in as ambiguous delays or confused corrections. Systematic errors were to be kept below $0''.01$ arcseconds. The electronic instrumentation operated successfully over temperature ranges of from 12° to 95° Farenheit although an average temperature in the vehicle was about 65°F. On at least one occasion, an electrical storm caused a power failure and damage to the cesium clock. The clock was immediately replaced and a study initiated to determine why the K02 power supply did not protect the cesium clock. It was quickly determined that the K02 had also been damaged by the electrical activity. This pointed to the need for more levels of power filtering and backup battery supply. The damaged clock was quickly replaced and the program continued.

Most survey work, particularly geodetic point-positioning depends upon recording time of day to at least millisecond accuracy. Nanosecond and microsecond timing is not necessary; but older atomic clocks which no longer are capable of functioning adequately for high precision PTTI applications can and should be put to good use in field applications such as this. The only requirement is that the older atomic clocks must be capable of operating to at least 50 microseconds absolute accuracy under severe weather and field conditions. Most older atomic clocks which are still operable have had most problems eliminated and good advantage may be taken of the inherent reliability of the electronics of such clocks even though, for high precision PTTI applications, such older clocks are now unsatisfactory.

In conclusion a complete PTTI timing system, which had been brought from design to implementation in 6 weeks, successfully permitted taking on a new task---the determination of precise astronomical positions in the field. This system, which required high quality, reliable timing, has demonstrated a proven capability for collecting PTTI data at primitive field sites, including examination and, if necessary, editing the data in the field; and finally for easily and rapidly sending that data back to the home office.

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APPENDIX A

HP9915A EPROM BASIC PROGRAM

No.	Statement	Comments
10	ON ERROR GOSUB 390	For any error, go to subroutine 390
20	ERASETAPE	Initialize magnetic tape cartridge and create a directory on it.
30	CREATE "TEXT",15 @ CREATE "DATA",125,512	Create two files on the magnetic tape cartridge. The first file is named "TEXT" and consists of 15 physical records, each 256 bytes in length. The second file is named "DATA" and consists of 125 logical records, each 512 bytes in length.
40	OPTION BASE 1	Specifies that the lowest value of the index for an array is 1 rather than 0.
50	DIM D(60)	Define an array of 60 real numbers

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No.	Statement	Comments
60	OFF TIMEOUT 7 @ RESET 7	Disables any timeout interrupt on the IEEE-488 bus and then resets the IEEE-488 bus, returning it to its power on state. The HP9915A then sends Interface Clear (IFC) and then Remote Enable (REN) to the Fairchild Coupler.
70	ASSIGN#2 TO "TEXT"	Opens the "TEXT" file.
80	PRINT# 2 ; "NO TEXT DATA ENTERED ***************"	Writes the above data into the TEXT file to cause the file to be properly initialized (null files cannot be processed).
90	ASSIGN# 2 TO *	Close the TEXT file.
100	ASSIGN# 1 TO "DATA"	Open tick file "DATA"
110	ON KEY# 1 GOTO 360	END processing. If button No. 1 is pushed, go to program segment starting at statement 360.
120	ON KEY# 2 GOTO 440	1'st Difference processing. If button No. 2 is pushed, go to program segment starting at statement 440
130	ON KEY# 3 GOTO 630	TICK processing. If button No. 3 is pushed, go to program segment starting at statement 630.

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Star Observation Mode---Default Mode.

No.	Statement	Comments
140	ON TIMEOUT 7 GOTO 270	If a timeout occurs on the IEEE-488 bus, go to program segment starting at statement 270. This timeout will normally occur after the astrolabe has transferred 24 ticks and ten seconds have elapsed since the 24'th tick.
150	SET TIMEOUT 7;10000	Set the timeout interval on the IEEE-488 bus to ten seconds.

160	ON INTR 7 GOTO 200	BEGIN MAIN ACQUISITION LOOP. If a service request is received from the Fairchild Coupler, then the Datatron has recorded a tick and wishes to transfer the tick to the HP9915A. The Fairchild Coupler raises the SRQ (Service Request) line to the HP9915A and, if statement 170 below has enabled this SRQ interrupt, then the HP9915A will branch to the program segment beginning at statement 200. Note that after the branch to statement 200 another SRQ interrupt will not be serviced until a subsequent ENABLE INTR 7;8 statement has been executed.
165	RESET 7	Reset IEEE-488 bus, issue IFC and REN.
170	ENABLE INTR 7;8	Enable SRQ (Service Request) interrupts from the IEEE-488 bus (bit 3 in control register CR1 is set on)
180	V=SLITE(0,1) @ V=SLITE(0,-1)	Turn the top (0) HP9915A light on (1), then turn it off (-1).
190	GOTO 180	Loop. This is an idle loop which is used to keep the HP9915A busy while waiting for a service request from the Datachron/ Fairchild coupler.
200	OFF INTR 7	A service request SRQ has been received from the Datatron/Fairchild coupler. First disable the ON INTR 7, GOTO 200 instruction at statement 160
210	V=SLITE(2,1)	Turn the third (2) from top HP9915A light on.
220	FOR R=1 TO 60 STEP 2	Inner Read Loop. Read in up to 30 ticks. The step increment is 2 because both the tick and twice the tick will be stored in the array.
230	ENTER 700 USING "K" ; D(R)	This command unlistens all devices; then designates the HP9915A as listener; next designates the Fairchild Coupler as talker at address "00" on the IEEE-488 bus ("7"); and then allows the Fairchild Coupler to begin talking by setting the attention ATN line to false. Note that this command allows sub-sequent bus transfer activity to occur at intervals controlled by the Datatron/ Fairchild Coupler. There is no need to re-interrupt the HP9915A since the HP9915A is now waiting, or "Listening" to the Datatron/ Fairchild Coupler. Each time SRQ is now raised, SRQ is ignored because it has been

		disabled. Each tick data transfer is indicated complete by the Line Feed that occurs when a tick has been transferred to the HP9915A, and not by using the SRQ interrupt. The USING specification of "K" means that the string or numeric field is entered in the so-called "free field" format. For numeric data, the number is left justified (with leading space or sign) and filled on the right with blanks.
240	D(R+1)=D(R)*2	Double the tick value to form the check number.
250	BEEP 10,100	Beep at 2500 Hz for 0.04 sec.
260	NEXT R	End Inner Read Loop for Datachron/ Fairchild coupler. The inner read loop is normally ended by the ten second timeout set up by statements 140 and 150.
270	IF R<24 THEN RESET 7 @ BEEP 100,100 @ BEEP 100,100 @ V=SLITE(2,-1) @ GOTO 160	If less than 12 ticks were sent to the HP9915A while it listened for ticks, then beep twice (at 492 Hz for 0.2 sec each), ignore values, and go start over at statement 160.
280	RESET 7 @ BEEP 100,200 @ BEEP 200,200	Good data & more than 12 ticks. Beep at 492 Hz for 0.4 sec, then change tone to 261 Hz for 0.8 sec.
290	PRINT# 1 ; D()	Write the array D to the magnetic tape cartridge.
300	FOR R=1 TO 60	Loop to clear D to zero.
310	D(R)=0	
320	NEXT R	
330	BEEP 200,100 @ BEEP 100,200	Beep at 261 Hz for 0.4 sec, then change to 492 Hz for 0.4 sec. to tell observer that he can now observe another star.
340	V=SLITE(2,-1)	Turn third from top HP9915A light off.
350	GOTO 160	END MAIN ACQUISITION LOOP

End Star Observation Mode (Default Mode)

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END Button Routine

360	ASSIGN# 1 TO *	Close file "DATA"
370	V=SLITE(4,1)	Turn fifth from top HP9915A light on.
380	END	Stop HP9915A processor

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General ERROR Routine

This routine handles all errors.

390	IF ERRN=67 THEN CREATE "TEXT",15 @ CREATE "DATA",125,512 @ RETURN	If no file error, then create the "TEXT" and "DATA" files and return.
400	DISP "ERROR"; ERRN;"ON LINE";ERRL	This line displays on the TV monitor a message which reads "ERROR error-number ON LINE line-statement-number". The error numbers are those in appendix E of the HP85 Owners Manual and Programming Guide (00085-90002 Rev. D 1/81).
410	V=SLITE(6,1) @ V=SLITE(7,1)	Turn on the bottom two HP9915A lights.
420	BEEP 100,10000	Beep at 492 Hz for 20 sec. to warn observer that catastrophic error has occurred.
430	RETURN	Go return from error routine and attempt to continue anyway in hope that error was a fluke.

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Second Mode. (First Difference Program Segment).

440	ASSIGN# 1 TO *	Close the "DATA" file
450	OFF INTR 7	Disable the SRQ interrupt processing specified in statement 160 or 520
460	OFF TIMEOUT 7	Disable timeout processing specified in statements 140 and 150.
470	RESET 7	IFC and REN the IEEE-488 Bus.
480	OFF KEY# 3 @ OFF KEY# 1	Disable TICK and END buttons. Only the first difference button (KEY# 2) is to remain active. This key will be used to indicate that first differencing is to be ended.
490	ON KEY# 2 GOTO 60	When 1'ST DIFFERENCE button is pressed (a second time--- the first time is to enter this mode) this program segment is ended and the normal default program segment is restored.
500	SET TIMEOUT 7;5000	Datachron must transfer ticks within 5 seconds if a timeout is not to occur. HP9915A does not remain in a "Listen" mode for more than 5 seconds.
510	ON TIMEOUT 7 GOTO 450	If a timeout occurs, then the IEEE-488 bus is reset, IFC and REN issued and then instructions executed which terminate in the idling loop at statements 530 and 540.

520	ON INTR 7 GOTO 550	If Datachron/Fairchild Coupler issues a SRQ, then go put HP9915A in listen mode and Coupler in talk mode.
530	ENABLE INTR 7;8	Allow SRQ interrupts to occur.
540	V=SLITE(1,1) @ V=SLITE(1,-1)	@ GOTO 530 Turn second HP9915A light from top on, then off, then loop back. This is an idling loop while waiting for SRQ from Datachron/Fairchild Coupler.
550	ENTER 700 USING "K" ; D1	
		Put HP9915A in listen mode; put Datachron/Fairchild Coupler in talk mode; drop ATN line and let Datachron/Fairchild coupler transfer time tick to HP9915A. Data transfered goes into variable D1.
560	BEEP 10,100	Beep at 2500 Hz for 0.04 sec.
570	DISP D1	Display the tick on the video monitor.
580	ENTER 700 USING "K" ; D2	Put HP9915A in listen mode again; talk mode for Datachron/Fairchild Coupler; and transfer another tick. But this time put tick into another variable D2
590	BEEP 10,100	Beep at 2500 Hz for 0.04 sec.
600	DISP D2;D2-D1	Display tick and first difference.
610	D1=D2	Make current tick previous tick
620	GOTO 580	Go get another tick and loop indefinitely. Loop is ended by pressing 1'st Difference button or by 5 sec. timeout set up by statements 500 & 510.

End Second Mode (First Difference Segment)

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Third Mode. (Fast TICK processing, Button No. 3).

630	ASSIGN# 1 to *	Close file "DATA"
640	OFF INTR 7	Disable interrupt processing set up in statement 150 or 710.
650	OFF TIMEOUT 7	Disable timeout processing set up in statements 140 and 150.
660	RESET 7	Reset IEEE-488 bus, issue IFC and REN.
670	OFF KEY# 2 @ OFF KEY# 1	Disable END and 1'ST DIFFERENCE buttons.
680	ON KEY# 3 GOTO 60	When TICK key is pressed again, go restore normal processing and recording of ticks.
690	SET TIMEOUT 7;5000	Allow HP9915A to wait in listen mode for no more than 5 seconds when waiting to receive ticks from the Datachron/Fairchild Coupler.
700	ON TIMEOUT 7 GOTO 640	If HP9915A waits too long (more than 5 sec), then go to statement 640, reset IEEE-488 bus, and execute code which ends in idle loop at statements 720 and 730. This prevents the HP9915A from sitting endlessly in a listen mode waiting for the Datachron/Fairchild coupler to do something.
710	ON INTR 7 GOTO 740	When SRQ comes in from Datachron/Fairchild coupler, go place the HP9915A in listen mode and the coupler in talk mode.
720	ENABLE INTR 7;8	Allow Datachron/Fairchild coupler to cause interrupt.
730	V=SLITE(3,1) @ V=SLITE(3,-1) @ GOTO 720	HP9915A turns fourth light from top on, then off, then loops back to previous statement in an indefinite idling loop. Loop is ended when a SRQ from Datachron/Fairchild Coupler comes in.
740	ENTER 700 USING "K" ; D1	Place HP9915A in listen mode, coupler in talk mode, make ATN false to allow coupler to talk. Put tick into variable D1
750	BEEP 10,100	Beep at 2500 Hz for 0.04 sec.
760	GOTO 740	Loop indefinitely. Loop is ended by either timeout of 5 seconds or by pushing the TICK button again.

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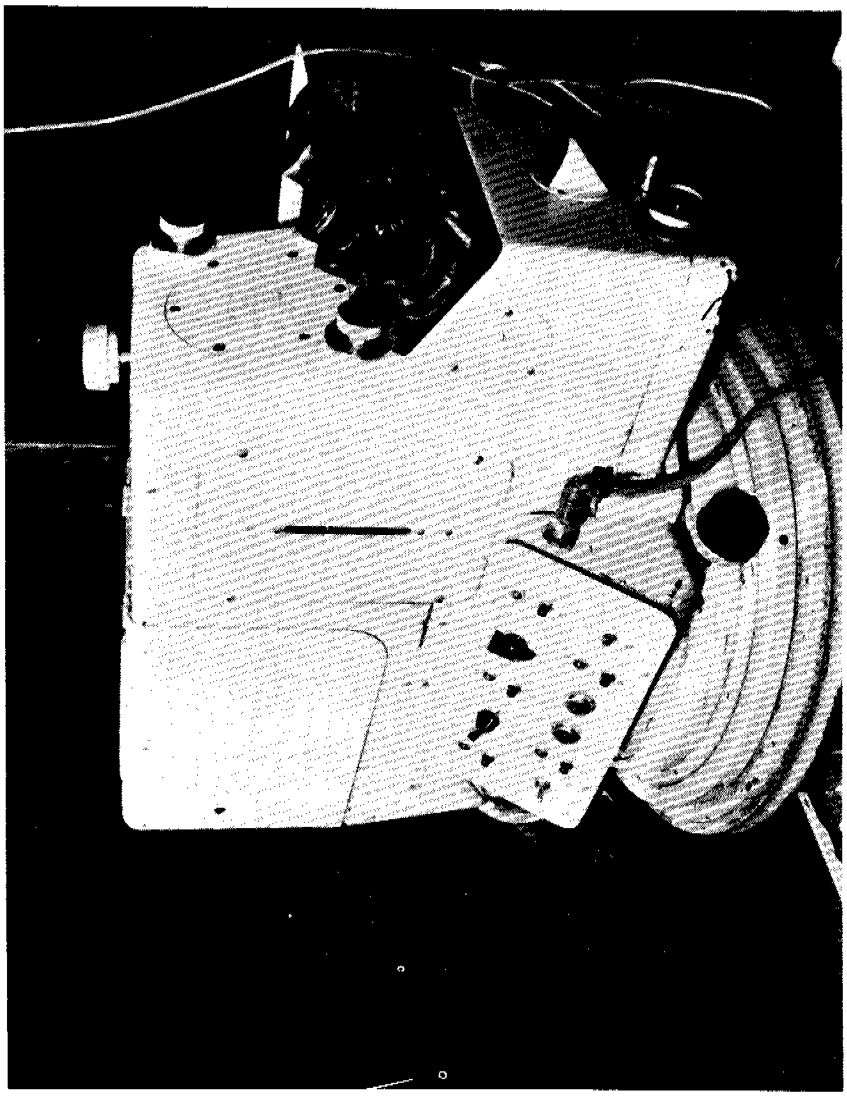

Figure 1. Danjon Astrolabe.

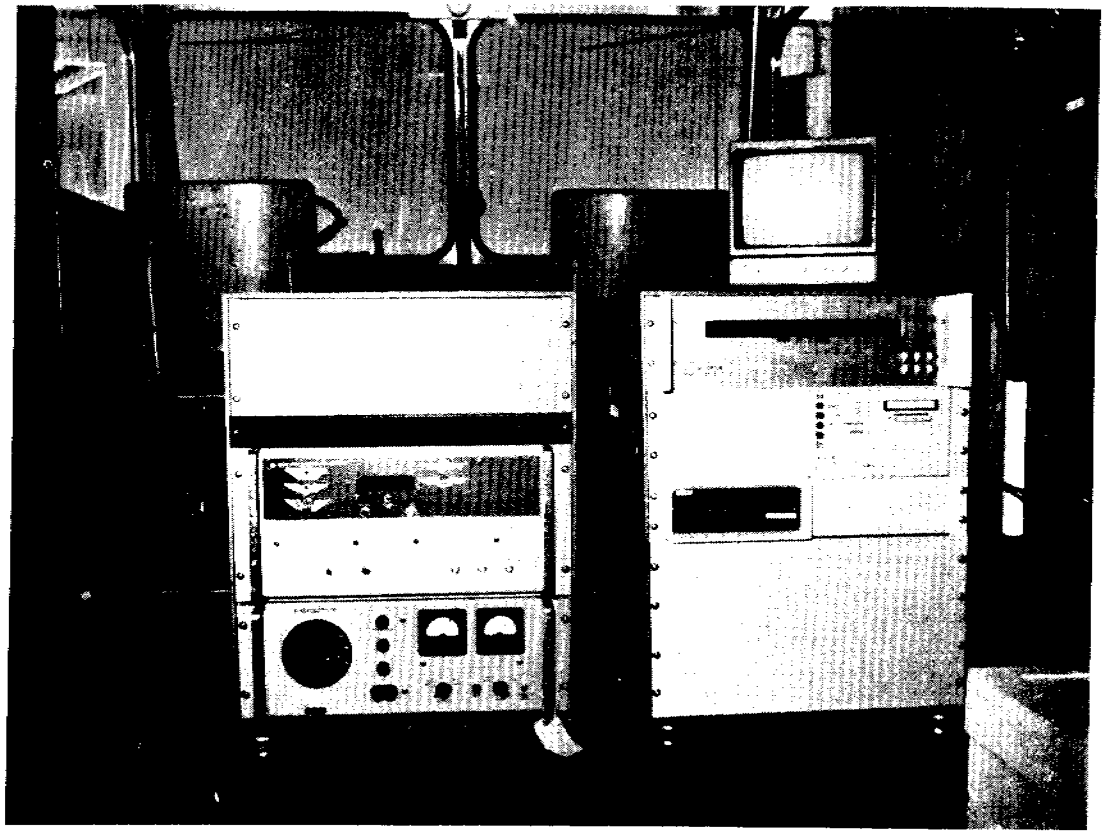

Figure 2. General View of Data Acquisition and Timing System showing cesium standard, TV monitor, Datachron, 9915A computer, and 4880 Interface Coupler.

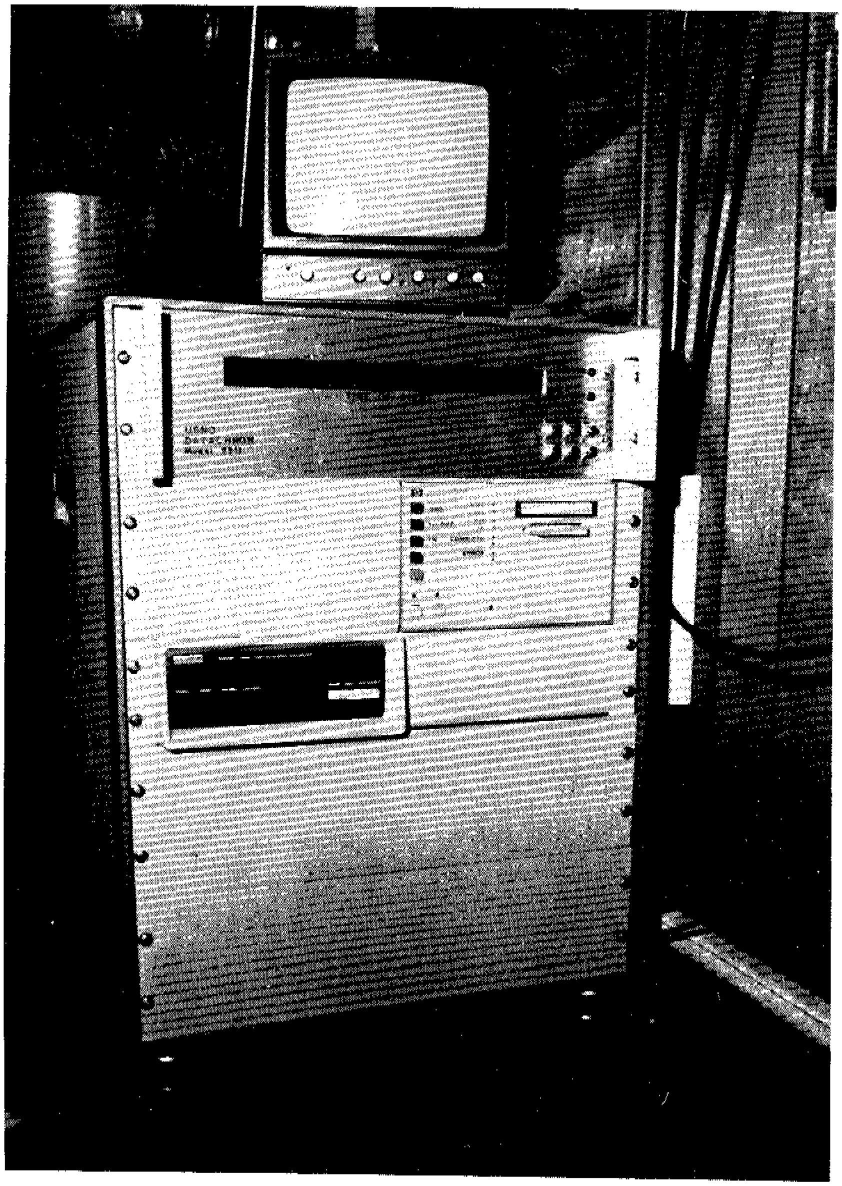

Figure 3. Data Acquisition and Timing System.

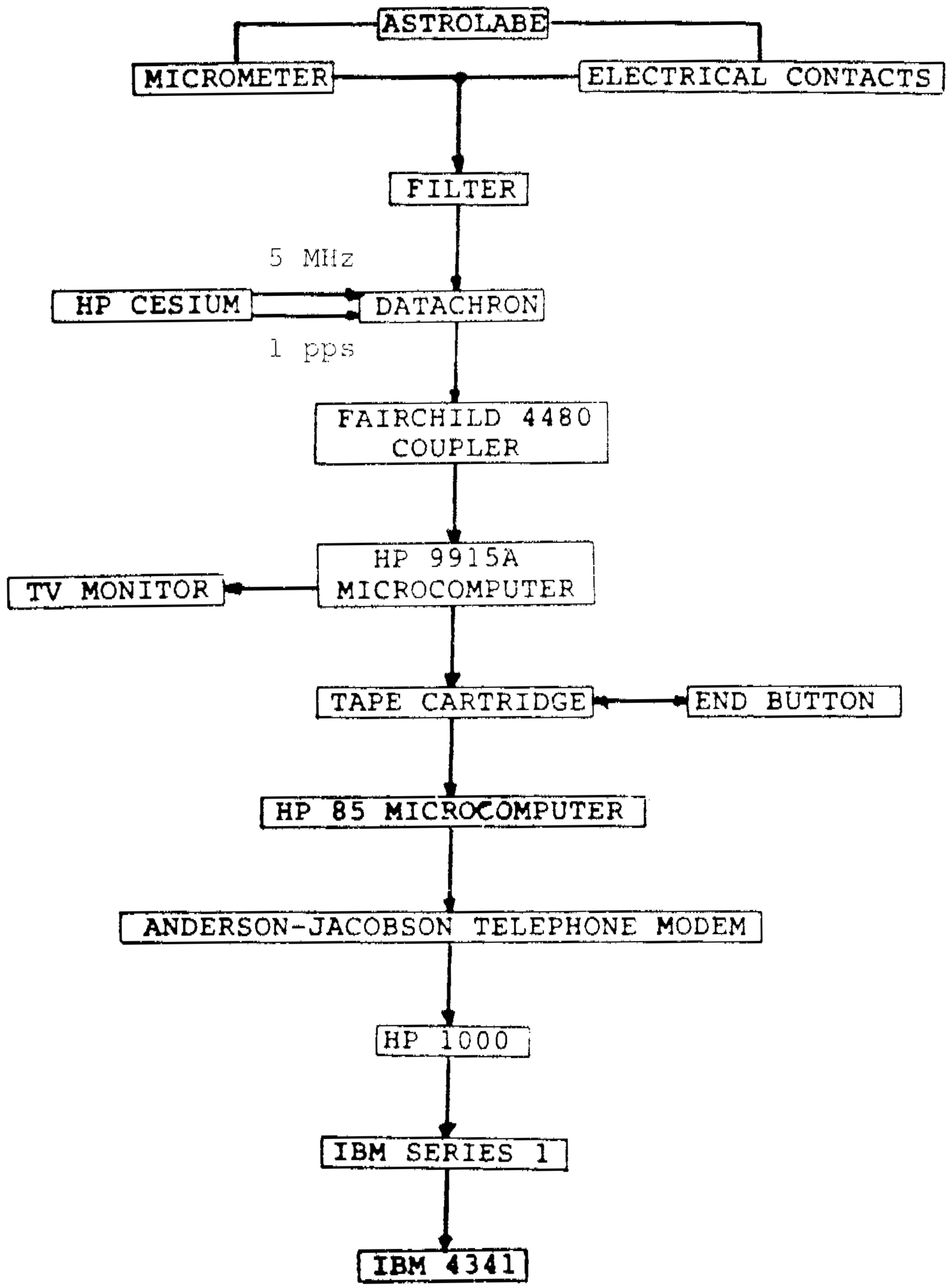

Figure 4. Time Measurement and Transfer System.

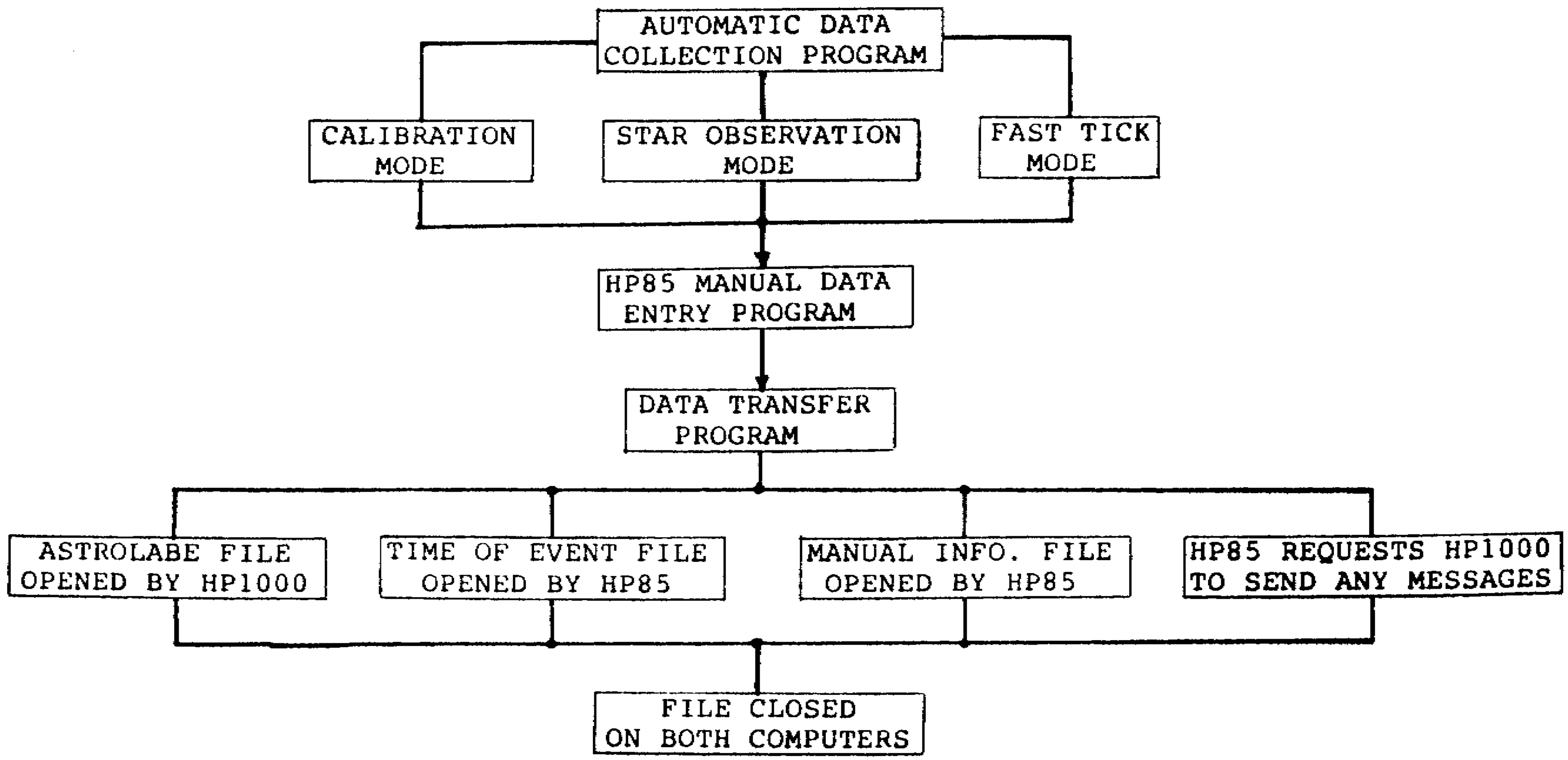

Figure 5. General Software Diagram.

QUESTIONS AND ANSWERS

None for Paper #22.