TIMING AND DATA ACQUISITION SYSTEM FOR A FIELD 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 and data acquisition system, gives engineering design considerations, and describes the equipment and instrumentation.

INTRODUCTION

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.

A search for a high-precision mobile field instrument capable of astronomical position determinations that would significantly improve knowledge of the deflection of the vertical at specific geodetic reference locations led to consideration of various observatory instruments. The Danjon Astrolabe was selected for a field evaluation of its ability to do this work because its accuracy and mobility make it well suited for high precision astro-geodetic work. Indeed, when Danjon designed his Astrolabe, he envisioned astro-geodetic work as the primary application of his instrument. The optical Danjon Astrolabe can determine position to within one meter accuracy and, to achieve the full accuracy inherent in this instrument, 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 (Figure 1).

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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 fundamental stars 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.

Figure 1. Astrolabe and shelter being installed at field 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 conditions (e.g., poor and unreliable electrical power, 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 an 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 by timing stellar images as the star, in its diurnal sidereal path, crosses the 30° almucantar. 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 Figure 2 could be used inside the vehicle or outdoors next to the Danjon Astrolabe.

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

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 (Figure 2) consists of an 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.

Micrometer contact signals are sent from the astrolabe to the 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 Datachron. The cesium clock operates continuously off an HP K02 power supply. 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.

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 the current time of day into a digital register. 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 of the Proceedings of the 15th Annual PTTI Meeting.

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. But contact wear and bounce may cause more or less than 24 ticks to occur. Accordingly, the program sets a limit of 30 recorded ticks for each star. As many as 90 stars were observed each night and recorded on the magnetic cartridge. At the end of the night, the observer presses the "END" pushbutton to terminate tick recording operations. The operator then removes the magnetic tape cartridge containing the recorded tick data.

Timing data on the cartridge was combined with hand recorded environmental and instrumental data, observer comments, and other messages. This was accomplished using an HP85 computer which was connected to an Anderson-Jacobson 1200 baud telephone modem. By dialing the Naval Observatory HP1000 computer over the switched public telephone net, the data on the tape cartridge was transferred daily to the Naval Observatory. The data was then transferred 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 Remote Job Entry (RJE) link or by magnetic tape. 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 there is a high probability (higher than 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. As a check on the accuracy of the transmitted data, both the recorded time measurement and its doubled value were transmitted. 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 was anticipated. Fortunately the problems with the HP1000 were not so severe that data transfer was disrupted in ways which would have endangered field operations.

PROGRAM OPERATION

The software for this system, shown in Figure 3, 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 for automatic capture of the astrolabe timing signals in the HP9915A 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

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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 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.

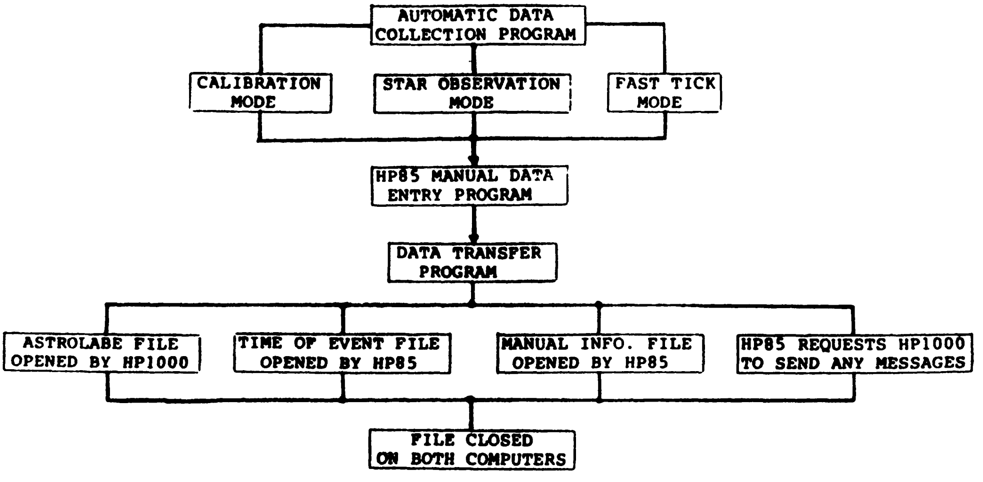

Figure 3. General Software Diagram.

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 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, number of ticks per revolution, 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 and provides the telephone numbers needed by displaying them on a small video screen. When the operator hears the HP1000 answering tone, the operator immediately places the telephone into the cradle of the 1200 baud Anderson-Jacobson modem. A special high quality transmission microphone (a Novation "Super Mike") is 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 allows 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 computers closed their data files, sent each other "GOODBY", and hung 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 six weeks preparation. The reliability was outstanding for field operations and was proven under severe weather conditions. Uncertainties in star positions require star transits be timed 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. Accordingly, the timing system used provided considerably more numerical precision than actually needed because of other limitations. The electronic instrumentation operated successfully over temperature ranges of from 12° to 95° Farenheit although the average temperature in the vehicle was about 65°F. On 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.

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 field conditions. Older atomic clocks which are still operable generally 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 six 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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