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Automated Timekeeping II — Source link

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Automated Timekeeping II

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***Abstract*—An automated system presently used by the U.S. Naval Observatory (USNO) for determining, maintaining, and disseminating Precise Time and Time Interval (PTTI) to a worldwide community of scientific and military users is described and evaluated on the basis of present capabilities and future requirements. The objective of the system is to provide near-real-time dissemination of PTTI information from a Master Clock time scale with a stability in excess of a few parts in 10^{-14}.**

BACKGROUND

IN 1972, an automated system for PTTI at the USNO was described at the Conference on Precision Electromagnetic Measurement [1]. The background information presented at that time remains essentially correct; however, in the ensuing years, a number of enhancements aimed at improving the Master Clock, signal distribution, measurement, data collection, data processing, data dissemination, and control systems have been developed and the extent of the services provided significantly expanded. The impetus and funding for these projects were the result of internally generated needs and externally recognized requirements which culminated in a formalized program entitled the Master Clock Upgrade (MCU). The MCU has resulted in significant improvements to the Data-Acquisition System (DAS) hardware and software systems, measurement subsystems, and the environment in which clocks are housed, with additional improvements planned for the clock systems and internal signal distribution.

The system is represented by the combination block/flow diagram in Fig. 1. It consists of five major subsystems: data acquisition, data measurement, clock and signal distribution, PTTI monitoring, and PTTI dissemination. In additon, there are ancillary subsystems for data collection, processing, and dissemination which can utilize one or more of the primary subsystems as part of their function.

On a scheduled basis, the data-acquisition subsystem computers go through programmed routines which control the operation of the peripheral data collection and measurement subsystems and thereby acquire data on each clock, monitoring system, astronomical instrument, or environmental condition that is locally accessible. Additional data are gathered by using dial-up telephone lines which provide access to remote measurement systems at selected Precise Time Stations (PTS) which have been equipped with suitable telecommunications facilities and by using an on-line TWX/Telex line which is

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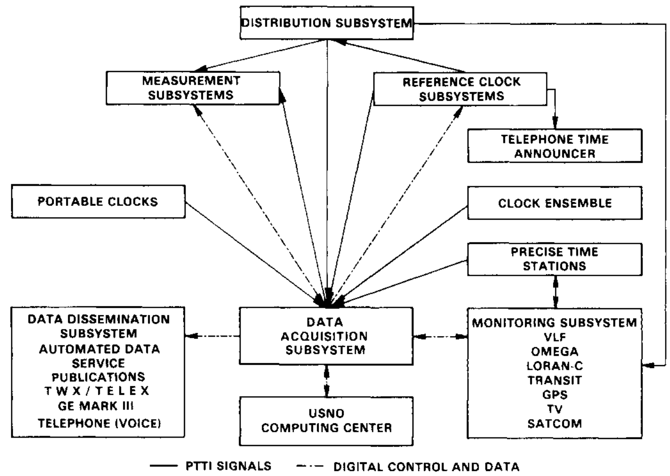

Fig. 1. Automated timekeeping system.

directly connected to the computer systems. An additional volume of data in nonmachine readable form must be manually processed.

A major tenet of the design philosophy used in putting this system together was and continues to be that of assuring data availability and veracity through redundant, independent hardware systems collecting sufficiently replicated data set to allow analysis and reductions having high confidence levels. As a result, huge amounts of data are collected and processed on a daily basis. On a typical day it would not be unusual for as many as 5000 clock intercomparisons, 600 Loran-C measurements, 800 Global Positioning System (GPS) data sets, 300 Omega and VLF readings, 100 Transit satellite values, 50 TV Line 10 measurements, 400 time "ticks" from astronomical instruments, 500 measurements at remote PTS, and several hundred data from TWX/Telex messages, letters, and portable clock trips to be recorded and processed.

During 1 h of a typical workday, one could typically expect to see the intercomparison of the complete Master Clock ensemble with each reference clock system, measurement of all pertinent environmental conditions in sensitive areas, the automated steering of the phase microsteppers in the reference clock systems, the intersystem transfer of PTTI data received via TWX, the accessing of measurement systems at PTS in Hawaii, California, and Florida, the measurement of all Loran transmissions which can be monitored at the USNO, and the recording of data from a current Transit satellite pass, all with no human intervention. At other times, one could observe the preparation of photo-ready master copies of Time Service Announcements, the reduction of a dozen GPS satellite passes, a search of procurement files for a missing request, or the preparation of a financial management report; all accomplished with a few keystrokes on the system terminal.

In addition to the main subsystems, there exists a growing number of ancillary subsystems whose primary functions are to improve the quality of data collected and the efficiency of the collection process and to provide a timely, easily accessible, cost-effective means of disseminating information to the user community. New, independent monitor systems installed at the USNO (GPS [2], Transit [3], automatic Loran, and Omega) are the forerunners of a growing number of mini- or microcomputer-controlled equipments that are components of a distributed network of independent data-acquisition systems with communications capability. The dissemination capabilities are designed to provide data as quickly as possible by means of techniques which are cost effective, readily accessible to a majority of users, and capable of expansion and upgrading to meet future needs.

Data-Acquisition Subsystem

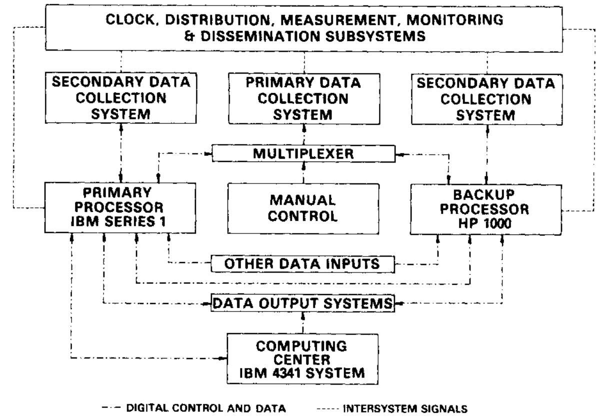

Fig. 2. Data-acquisition subsystem.

The purpose of the DAS (Fig. 2) is to collect, process, and disseminate (internally) PTTI data and to provide the means for automatic control of timekeeping functions in as reliable and cost-effective a manner as possible. As data are available from a variety of sources ranging from raw, digital data from electronic measuring systems to processed data in printed form from participating PTS, a wide variety of input capabilities are necessary. Clock and local PTTI monitoring (Loran-C, VLF, Omega, etc.) are accomplished by directing coherent analog and digital signals to measurement systems and recovering the results over data communications lines. Partially processed data are transferred from a GPS receiver on magnetic-tape cartridges, from Transit and Omega receivers over a multiplexed RS-232C line, from directly connected TWX/Telex lines, from fiber optics and coaxial intercomputer data communications links, and from written hardcopy via computer terminals.

Signals are directed to measurement systems through a combination of the old switching subsystem (primary) and new IEEE-488 general-purpose instrumentation bus (GPIB) compatible switch modules (secondary) which make up the data collection systems. The primary system also includes the switching and signal conditioning used to make environmental measurements at various locations at the USNO. The primary data-collection system is under the control of a multiport, USNO designed multiplexer which can be accessed by any of up to four controllers on a defined priority basis. The secondary data-collection systems add an additional dimension to the system in the sense that they are expandable in size and number and that they can be remotely located and conveniently operated by various controllers over data communications links.

The processor/controllers are an IBM Series 1 which serves as the primary system and an HP 1000 which serves as backup. In addition to the applications that are common to both systems, each has a unique set of functions peculiar to its physical and functional location and each has developed a "personality" which is a composite of that of the operating personnel and their organizational function. As a consequence, the primary system or "upstairs" (by virtue of its location) DAS, is operated by astronomer and mathematician programmers, and is configured to meet the needs of the data analysis, time scale, and astronomical portion of the USNO PTTI mission. On the other hand, the backup system, or "downstairs" DAS, is operated by engineer, technician, and mathematician programmers and is configured to perform functions in the monitoring, dissemination, and operations portion of the mission.

The input/output capabilities of both systems include standard peripherals such as magnetic tape, paper tape, and a variety of terminals. Each also has a variety of digital I/O capabilities (bit parallel, synchronous, and asynchronous serial, and IEEE-488). Unique aspects of the primary system include direct connections to the USNO Computing Center, to another Series 1 system dedicated to astronomical and off-line functions, and to Western Union TWX/Telex lines. The data base and operating system are configured and tailored to perform the unique functions required for data analysis and clock system control. The secondary system includes an extensive telephone communications capability, access to specialized measurement systems, advanced graphics capabilities, multipoint and multidrop terminal capabilities, and a data base and operating system tailored to perform data communication, operational functions, and data dissemination.

A fiber-optics link to the Computing Center provides high-speed access to the large data-base storage capability and computational power inherent in a large-frame computer system.

Measurement Subsystem

The measurement systems presently in use (shown in Fig. 3) are much more versatile and easier to implement than their prececessors by virtue of their capability of operating on the IEEE-488 bus. The combination of bus operation with microprocessor-based instrumentation has led to a significant reduction in the size and complexity of hardware and wiring. Additional benefits of measurement implementation using instrumentation bus concepts include ease in system construction and modification, "portability" of software, ease of upgrade as new instruments are developed, and versatility of

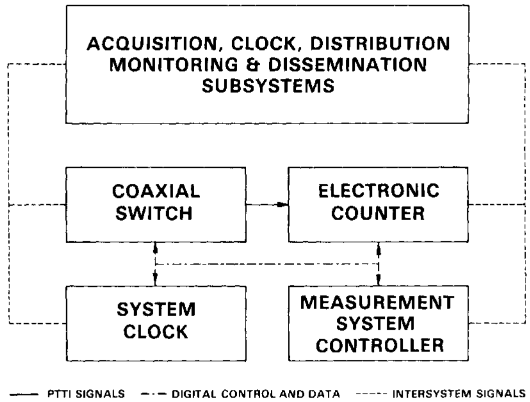

Fig. 3. Measurement subsystem.

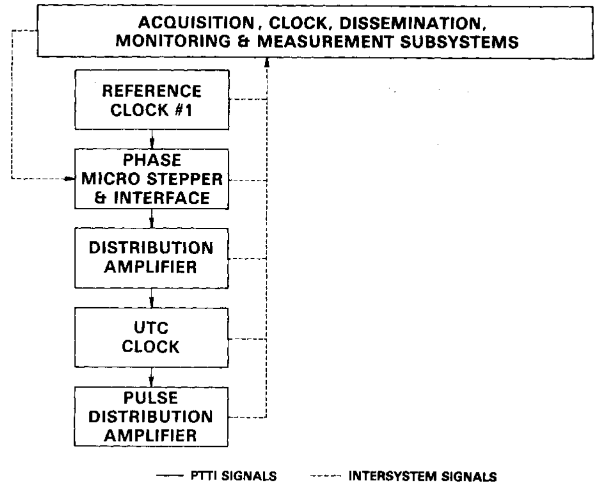

Fig. 4. Signal-distribution subsystem.

system configuration which allows a single systems design to function in multiple environments.

The measurement system consists of a programmable electronic counter, a time-of-day clock, and a measurement system controller, all of which are GPIB compatible. The counter can be any one of a number presently available, the choice being which parameters are to be measured (time interval, frequency, voltage, etc.) and to what precision and accuracy the measurement is to be made. The system clock provides a precise time tag for any measurement made and thus allows precise chronological ordering of data, a necessary condition if measurement noise is to be minimized. It also allows the application of simultaneous measurement techniques to spatially separated systems. The controller can range from a directly connected GPIB interface on the DAS, or a separate microcomputer directly connected to the DAS or (either) connected to the DAS via data communications hardware. Depending on the configuration, data transfer may be either direct store to the DAS or local store and later forward on request. In either case the result is the same, for each program-directed measurement that is made, a precisely defined, chronologically identified datum point is collected and stored.

Clock and Signal Distribution Subsystem

The clock subsystem implementation has remained relatively unchanged over the years since it was first put in place. This is particularly true in regard to the concept of an "ensemble" of atomic clocks located in several independent "clock vaults," the algorithm used for constructing the "paper reference" upon which the Master Clock is built and the physical realization and distribution of the Master Clock through the use of redundant reference clocks, phase microsteppers, clock/dividers, and distribution amplifiers (Fig. 4). Improvements have been realized, however, in the development of a hardware interface which allows fail-safe automated control of the microsteppers, the development of improved microsteppers and digital clocks, and the control of the environment in areas housing clocks. As a result, the time scales developed are defined to better than a few parts in 10^{-14} for averaging times greater than one day. In addition, reference clock differences can be held to less than 50 ns from day to day, and reference clock one-pulse-per-second signals are well defined (nanosecond rise times) and stable (subnanosecond jitter). Continued refinements of the clock subsystem are dependent on the addition of improved clocks to the ensemble and the development of better models and algorithms.

One of the more critical areas of timekeeping is the distribution of signals to various measurement and monitoring subsystems without degradation. The problem is particularly acute at the USNO due to the distributed nature of the system clocks, monitoring systems, and measurement systems. In such an environment, achieving much beyond present capabilities will require a significant effort. The present system configuration (Fig. 4), although adequate for system operation until recently, is limited to its present level of performance. Improvements that were implemented over the past ten years include the use of state-of-the-art clocks and distribution amplifiers to assure stable, well-defined one-pulse-per-second reference signals at measurement and monitoring subsystems and the installation of calibrated cables for signal distribution to critical measurement areas. The stability and noise problems that are part of any attempt to drive reference signals over any significant length of coaxial cable become quite visible as measurement techniques and clock systems are refined. The problem is made more acute by the fact that reference distribution amplifiers are the one system component whose degradation or replacement totally destroys the coherence of system operation. Improvement of the signal distribution system is probably the single area where an extensive redesign and reconfiguration could yield a significant, overall improvement in system performance.

PTTI Monitoring System

Although PTTI monitoring capabilities have undergone a significant transition from highly labor intensive to a high level of automation, the concept of redundant monitoring systems driven from redundant reference clocks remains valid. Manual

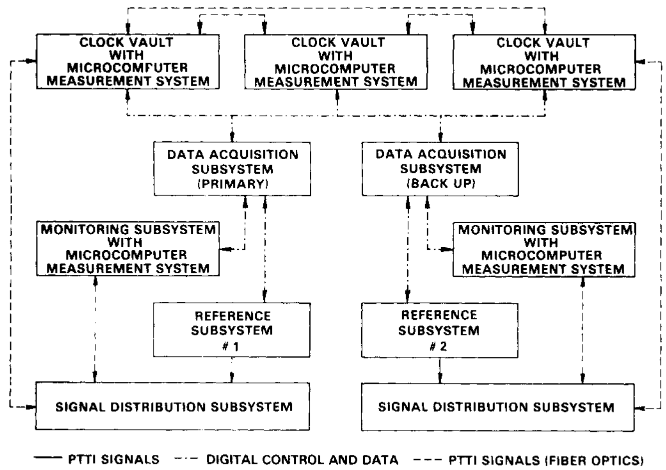

Fig. 5. Future configuration.

tracking receivers for VLF and Omega are queried hourly for phase information and every few minutes for off-air status. Similarly, precise time-of-arrival measurements are made hourly on TV and Loran-C transmissions. Prior to implementation of automated measurements, these data were taken by hand. The increasing availability of microprocessor-based, automated receivers has led to the completely "hands-off" monitoring capability for Loran-C, Transit, Omega, and GPS (late 1982) at USNO. In addition, automated PTTI monitoring at a GPS site in California, a SATCOM facility in Maryland, a Navy communications station in Hawaii, and the Eastern Test Range timing center in Florida have amply demonstrated the viability of remote, automated PTTI monitoring. Automated processing of TWX traffic has left only data received in written formats to be manually processed.

PTTI Data Dissemination

The single area which has benefited most significantly from automation is data dissemination. In the past, a significant effort on the part of a majority of USNO Time Service personnel was required just to produce a daily TWX message and a weekly bulletin. Now the data for these publications are taken, reduced, formatted, and outputted in finished form automatically. In addition to these traditional forms of distributing information, time-of-day announcements and the content of the TWX messages are available around the clock via dial-up commercial and military telephone lines as is access to a diverse real-time measurement, computational, and PTTI data base which is known as the Automated Data Service (ADS) [4]. ADS provides direct access to virtually all data produced by Time Service to anyone with a data terminal and telephone line.

Future Plans

In order to maintain its preeminent position in the international timekeeping community, the USNO has pursued an active program of upgrading all subsystems of the automated timekeeping system. Plans presently in progress include the addition of hydrogen masers to the clock ensemble, the purchase and installation of additional high-quality clock vaults, the improvement of the quality and reliability of primary power, uninterruptible power systems and emergency diesel generators, the decentralization and dispersion of measurement systems to clock vaults and monitoring facilities with fiber-optic distribution capabilities for reference signals (Fig. 5), the automation of more PTS, the expansion of the ADS, and continued improvement of the system algorithms and software. The introduction of masers into the clock ensemble, combined with an improvement in the environment in which the ensemble is housed, should significantly improve the stability of the USNO time scales, particularly at sampling times of less than a day. The improvement of the system algorithms and software will allow these improvements to be realized in the physical clock implementation. The elimination of interruptions in power will reduce data discontinuities and improve the reliability of hardware systems. The decentralization of measurement and monitoring facilities combined with signal distribution using fiber optics should improve both the stability of reference signals and the precision of measurements, and reduce the loss of clock data due to failures in a centralized DAS system. It is expected that the automated timekeeping system will continue to evolve to meet the increasingly stringent PTTI requirements foreseen in the future [5].

Acknowledgment

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