A COMPARISON OF TIME TRANSFER TECHNIQUES

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Abstract

In the development of timing systems for the Global Positioning System (GPS), a clock ensemble has been installed at the Master Control Station for GPS at Falcon Air Force Station, Colorado Springs, Colorado. A single-frequency, Clear/Acquisition (C/A) GPS receiver is integrated into that system to perform time comparisons with the U. S. Naval Observatory (USNO). Having data from these two sites provided an opportunity to compare different techniques for time transfer and to examine their relative merits and performance. Three basic techniques were examined: common-view, melting-pot, and non-simultaneous common-view. The results and a comparison of the different techniques will be presented.

INTRODUCTION

The NAVSTAR Global Positioning System (GPS), currently being deployed for operational use, is to provide accurate positioning capability for the Department of Defense and civilian use. One aspect of the system is its ability to disseminate accurate time for military and scientific users. The NAVSTAR developmental satellites, commonly known as Block I satellites, are being used for time comparisons between timing centers and other groups interested in maintaining very accurate time synchronization. The methods used to gather the data and perform time comparison have evolved into two basic types, the first typified by the user being passive, using only the information transmitted by the satellites, and the second being an active user. The active user incorporates data gathered at other sites communicated separately, or other external data, such as independent knowledge of accurate position. These two user types are the foundation for these two widely used methods of time transfer, known as the "Common View" and the "Melting Pot" techniques.

TIME TRANSFER TECHNIQUES

The basis for time transfer is the same as for navigation with GPS, that is, pseudo-ranging to the satellites. The pseudo-ranges are essentially time comparisons between the satellite clock and the clock in the receiver on the ground. The pseudo-ranging errors are either minimized through the data collection technique or through the system design features for satellite position, ionospheric and tropospheric delays and other contributing error sources. Experiments with GPS to determine absolute range accuracy from a single pseudo–range measurement, using the single frequency clear/acquisition signal have resulted in approximately a 15 meter uncertainty, including all system error sources. The overall behavior of the system, however, shows very consistent long term behavior resulting in quite repeatable measurements. Each of the different techniques takes advantages of the repeatability of the measurements to compare clocks.

The Common View technique, developed by the National Institute of Science and Technology[1,2] (NIST) involves two or more ground stations simultaneously observing a single GPS satellite and compiling the observed data at a central point or interchanging the data for the final time transfer determination. This technique is similar to interferometric observation of a single source by widely separated observers. By knowing the positions of the satellite from the broadcast message, and positions of the ground stations, from prior data or independent survey, the times–of–arrival of the satellite signals can be corrected for the transmission travel times and the two clock measurements differenced for the time transfer value. This technique attempts to eliminate the effect of the satellite clocks so that a direct comparison between the two remote clocks can be made.

Another method, the melting–pot technique, is currently in use by the U.S. Naval Observatory (USNO)[3]. In this technique, observations recorded from all satellite passes during a two–day period are combined to produce one time transfer value at the midpoint. The set of one–point–per–day data is then used to estimate the ground station time difference. This technique solves for an estimate of GPS Time, the GPS internal time reference, for each site taking observations. Another site can then difference its estimate of GPS Time, over a simultaneous observation time span, with that at USNO resulting in a time transfer between the two sites. For sites observing at non–simultaneous times, an estimate of GPS Time can be used to connect the two sites. This technique is also used to monitor GPS Time relative to UTC(USNO) as the mechanism for providing correction terms for the GPS broadcast message.

A third method under investigation is a non–simultaneous common view approach, by which a curve fit is made to the recorded data at each station for each satellite pass. Time transfer values are then calculated from data values estimated at selected regular times on the two curves. These time transfer values for all satellite passes can then be combined to estimate the clock difference for a specified time period.

DATA COLLECTION

The data used for analysis was collected from Day 86 (27 March) to Day 170 (19 June), 1989 at USNO and the Consolidated Space Operations Center (CSOC), Colorado Springs. The receivers employed were single frequency C/A and produced a corrected and smoothed pseudo–range value every 13 minutes. The largest source of error was expected to be from ionospheric correction since the broadcast correction model was used. These data from both CSOC and USNO have been referenced to GPS time ((CSOC – GPS) and (USNO – GPS)). Data was analyzed from all GPS satellites active during the time period: NAVSTAR's 3, 6, 8, 9, 10, and 11. A total of 4,199 points from USNO and 5,050 points from CSOC were used in the melting–pot approach, and 1,347 points were matched and used in the common view technique.

GPS systematic noise can introduce large biases in both USNO and CSOC data. Figures 1 through 3 show the biases on the data obtained via NAVSTAR 11 from USNO and CSOC, and on the resulting common view time transfer (USNO – CSOC) for an eight–day time span. Table 1 contains the statistics of the curve fits to these data sets.

Table 1. Statistics of Curve Fits for Eight–Day Data Sets

	Day 148 Calculated Clock Difference (Microseconds)	Frequency ($pp10^{-13}$)	Aging ($pp10^{-14}$)	RMS (ns)	No. Points Used
Fig 1.	-0.144	0.18	−1.2	8	58
Fig 2.	-2.544	−0.58	−1.1	15	155
(1-2)	2.400	—	—	—	—
Fig 3.	2.389	0.73	−0.5	11	56

ANALYSIS

Exactly simultaneous observations were not necessarily available for this study; therefore, a five-minute tolerance was used to select "matched" observations for the common view method. A time transfer value was calculated for each match in the 83–day span, for each satellite. A second–degree curve was fit to the set of time transfer values of each satellite, and a single value was estimated at the midpoint of the time span, Day 128. In addition, a second–degree curve fit was performed on the composite set of all satellite matches, and a single time transfer was calculated for Day 128.

Figures 4 and 5 represent partial sets of data (USNO – GPS Time), and (CSOC – GPS Time) used for the melting pot method before correlating for common view. Figure 6 presents all the common view time transfer values, (USNO – CSOC), for matched observations from the entire data set. Table 2 contains the statistics of the curve fits to these data sets.

Table 2. Statistics of Second Degree Fits to 83–Day Data Sets

	Day 128 Calculated Clock Difference (Microseconds)	Frequency ($pp10^{13}$)	Aging ($pp10^{14}$)	RMS (ns)	No. Points Used
Fig 4.	-0.186	0.08	0.0	21	4149
Fig 5.	-2.449	-0.79	0.1	29	5040
(4-5)	2.263	—	—	-	—
Fig 6.	2.254	0.88	0.0	20	1347
Fig 7.	2.265	0.87	0.0	10	76 *

** First degree curves were fit to each of the two–day data sets to produce the 76 points used here.*

For the time transfer calculations using the melting pot technique, a curve was fit to the two–day span of data centered on each day in the 83–day set for each station. Due to the data spread, a first–degree fit produced a more consistent calculation of the daily points. The daily points were differenced to produce daily time transfer values as shown in Figure 7. A second–degree curve was fit to the set of daily values to estimate the time transfer for Day 128, shown in Table 2.

CONCLUSIONS

The common view technique, using simultaneous observations, accurate satellite positions, and common receiver algorithms, provides time transfer values almost independent of the system and very stable day-to-day results. However, an estimated time transfer for a time span is only a function of a subset of the entire data base — the "matched" times. Communication of the gathered data determines the frequency of performing the time transfers, and can be done on demand as needed.

The melting pot technique uses all available data to estimate GPS Time as a basis for transferring time. The use of all the data should provide a more robust estimation of the state of the system. Since this technique actually correlates GPS Time to UTC(USNO), it provides a more general database for transferring time, rather than minimizing or eliminating the system from the time comparisons. It can also be used without a large transfer of data between sites, and by those who may have limited or no common observation times.

A comparison of the results of the two methods is shown in Table 2. The common view method produced a time transfer value of 2.254 microseconds with a 20 ns RMS, and the melting pot 2.265 microseconds with a 10 ns RMS. These value are roughly comparable although the melting pot solution should merit a higher confidence.

REFERENCES

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2. M. A. Weiss and D. W. Allan, "An NBS Calibration Procedure For Providing Time and Frequency at a Remote Site By Weighting and Smoothing of GPS Common View Data", IEEE Transactions on Instrumentation and Measurement, vol. 36, no. 2, pp571–578 [June 1987]

3. G.M.R. Winkler, private communication.

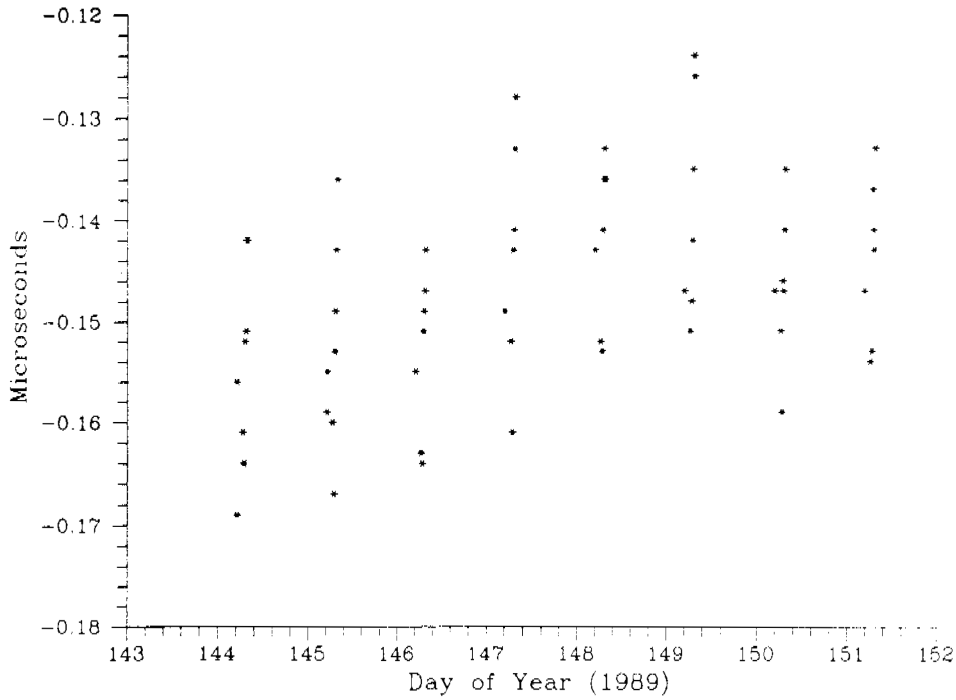

Figure 1. Clock Difference (USNO - NAVSTAR 11)

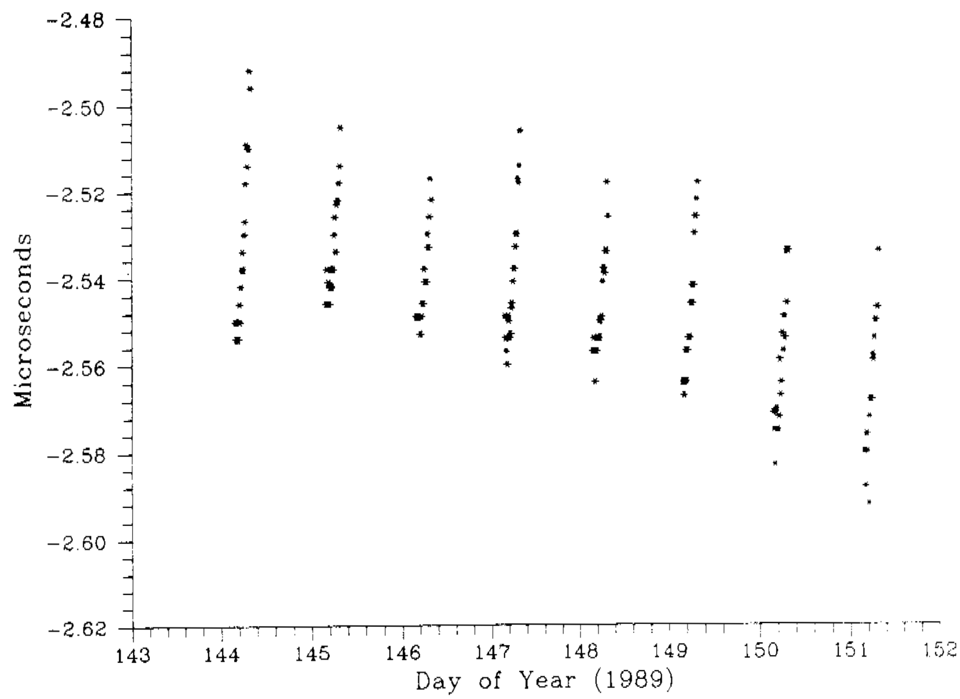

Figure 2. Clock Difference (CSOC - NAVSTAR 11)

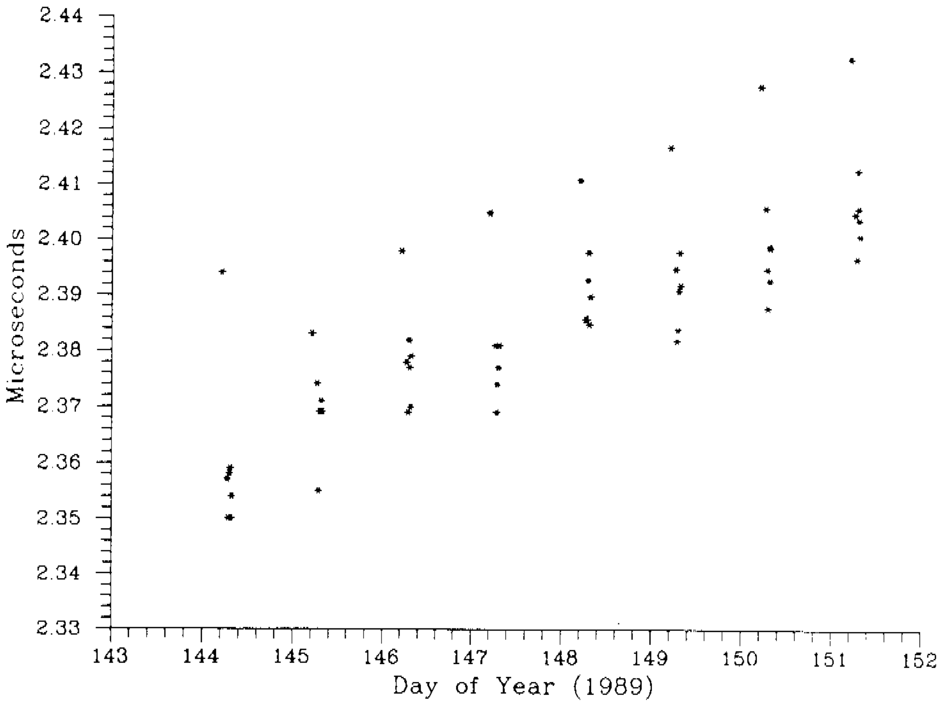

Figure 3. Common View via NAVSTAR 11 (USNO – CSOC)

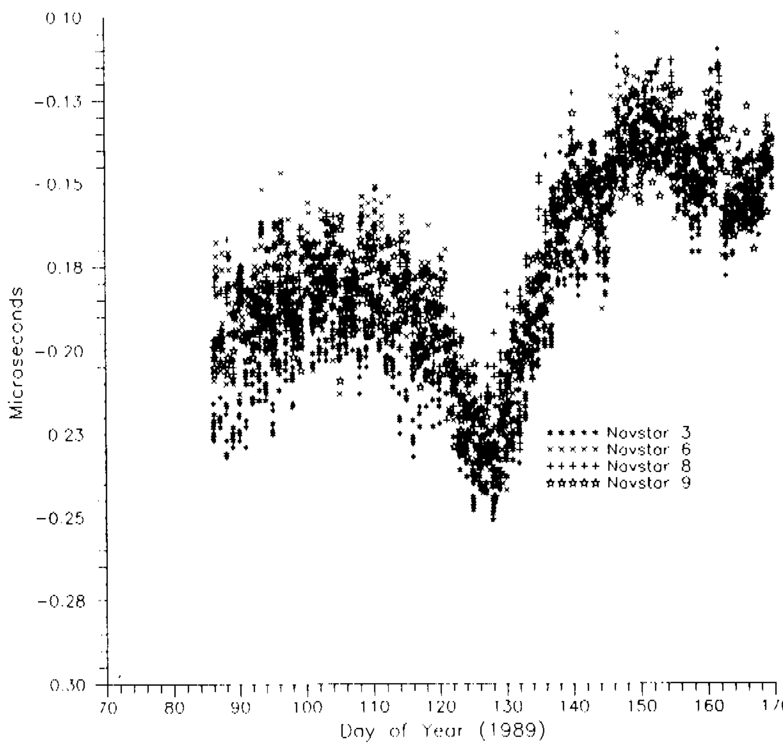

Figure 4. Clock Difference (USNO–GPS Time)

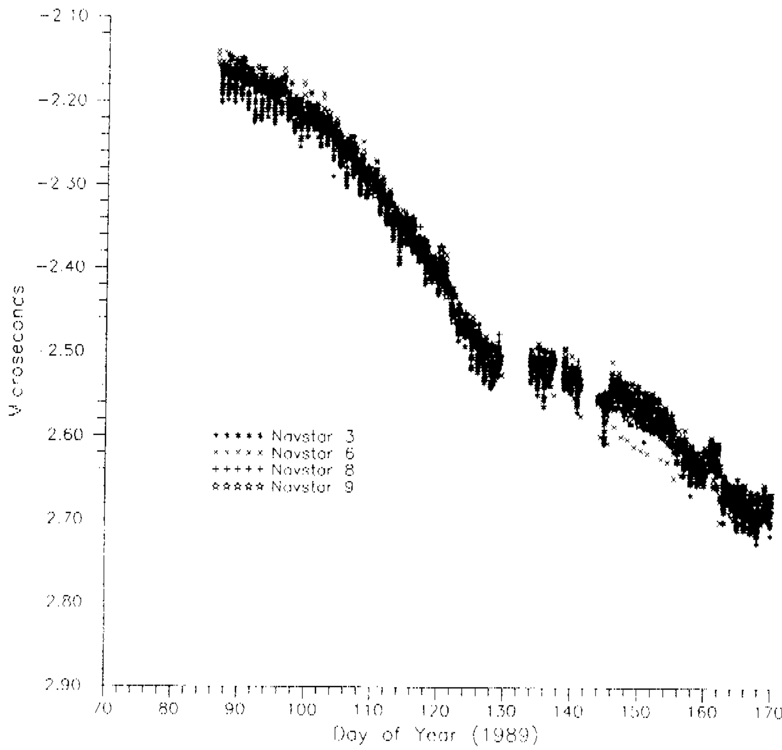

Figure 5. Clock Difference (CSOC GPS Time)

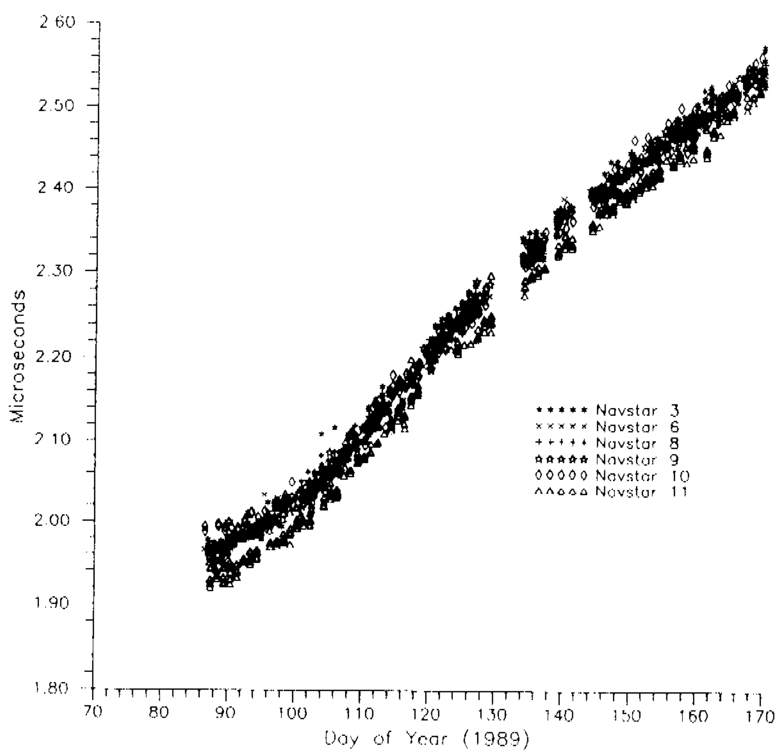

Figure 6. Common View via All NAVSTARS (USNO–CSOC)

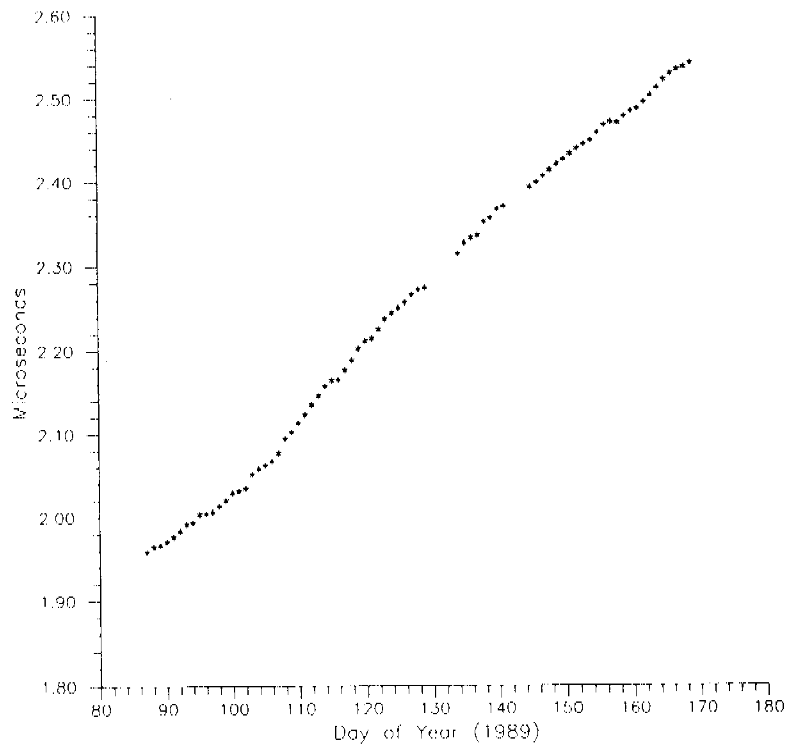

Figure 7 Melting Pot Time Transfer (USNO-CSOC)