Comparison of Frequency-scale Algorithms Using Atomic Fountain Data

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Abstract

Inspired by algorithms developed specifically for pulsar work [1-2], and the extremely precise data becoming available from atomic fountains [3], we have begun investigating the differences between possible algorithms that could be used for timing purposes. Initial comparisons are between Kalman-based and Fourier-based determinations. Although conclusions related to frequency scales will in general translate to time scales, the results in this printed version are to be considered extremely preliminary, as improved standards and more precise time transfer continuously make more and better-quality data available.

1. Introduction and Algorithmic Description

Coordinated Universal Time (UTC) is undergoing a burst of improvement due to lower noise frequency standards, improved time transfer, and algorithmic improvements [4, 5]. Among them is a method for keeping the International Bureau of Weights and Measures's (BIPM) preliminary free-running timescale (EAL) much closer in frequency to the primary standards. Because of this, no frequency steers to EAL have been necessary; the last catch-up steer to bring UTC's frequency closer to the primaries was on September, 2012 (MJD 56199). The frequency deviations between EAL and the primaries have also been minimal, with deviations of no more than a few parts in 10^{15} over a few tens of days.

As described in references [1] and [2], greater levels of precision are being achieved with respect to pulsar timing, and even higher precisions are anticipated. In those references, an algorithm is presented that accounts for red noise (long-term noise) in pulsars through a least-squares fit to deviations from Terrestrial Time (TT) along with other pulsar parameters. Deviations from TT can be parameterized as either a Fourier series or a piecewise continuous set of linear offsets. Since each pulsar contributes to the time parameter determinations only when data are available, the effects of sparse data are minimized.

Data from atomic fountains used as primary frequency standards were obtained by downloading data from the BIPM's anonymous ftp server; these take the form of 10-30 day average frequency differences between the standard and UTC, along with uncertainties. Some of those laboratories contribute primary standard data using a GPS-link while others use Two Way Satellite Time Transfer data. As an independent standard of truth, we used daily frequency averages from atomic fountains maintained at the U.S. Naval Observatory (USNO) and the Physikalisch-Technische Bundesanstalt (PTB).

We report initial attempts with algorithms: one uses a Fourier series and the other a Kalman filter. Since the USNO has four rubidium atomic fountains while only one of the PTB's two cesium fountains has a sufficiently long time series, only the USNO's NRF5 (the best) and the PTB's CSF1 (the longest time series) are used in this work. The USNO fountains are not frequency calibrated, and therefore an overall constant was subtracted from NRF5 which permitted the USNO and PTB data to be intermixed. Figure 1 shows the frequency difference between the two fountains, and Figure 2 displays the Allan variance of that difference.

2. The Fourier and Kalman Solutions

Using standard techniques, a sum of Fourier terms with periods from 1005 to a minimum of 20.1 days was fitted to the combined primary fountain data referenced to UTC. Including a constant term, 101 parameters were solved for. Kalman solution used only a single "constant" frequency offset parameter, with process noise arbitrarily set equal to the square of 0.1 ns/day from each point to the next. Figure 3 shows how these parameterization schemes fit the data, and suggest that the algorithms lead to similar results in this situation. Figure 4 differences the Fourier approaches with the combined Kalman backwards and forward solutions. It is evident that all solutions can correctly remove the artificial steers added to EAL prior to MJD 56199. In general the Kalman filter's single parameter does about as well

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as the Fourier series, and does not have the edge effects the Fourier solution showed at the very ends of the dataset – those are not understood at the time of this submission.

5. Conclusion

We have not found a large difference between a Kalman and a Fourier-based algorithm on the datasets used in this study, which can be considered well-behaved since they have few outliers and few gaps.

6. Acknowledgments

We wish to thank Andreas Bauch and the PTB for use of their atomic fountain data, and the USNO's Clock Development and GPS Operations divisions.

7. References

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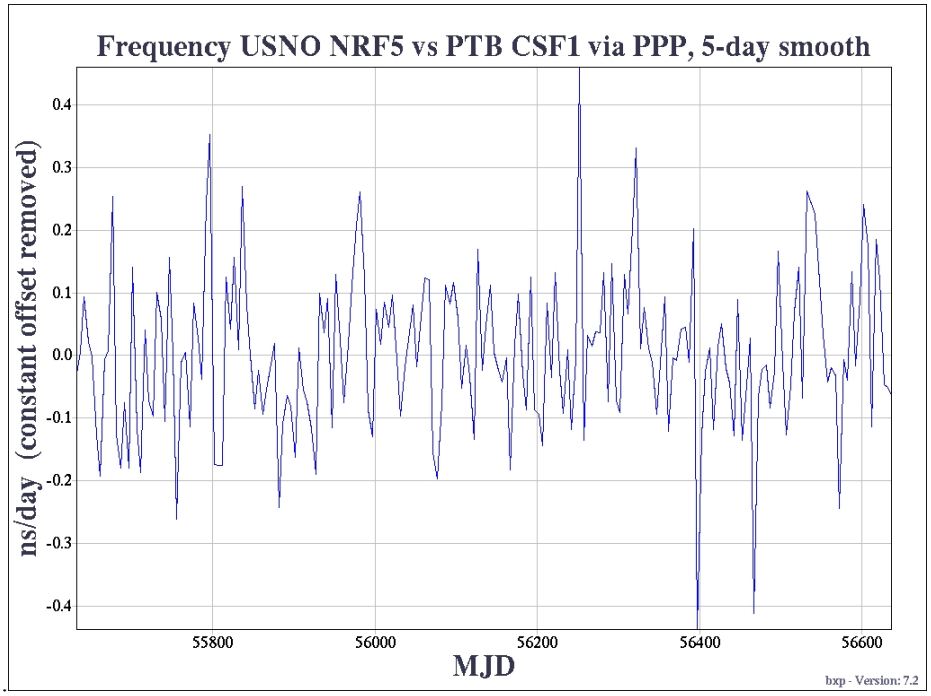

Figure 1. Smoothed frequency difference between fountains at USNO and PTB. Frequency-transfer is achieved via carrier phase GPS using data from the same receivers and software package used operationally by the BIPM.

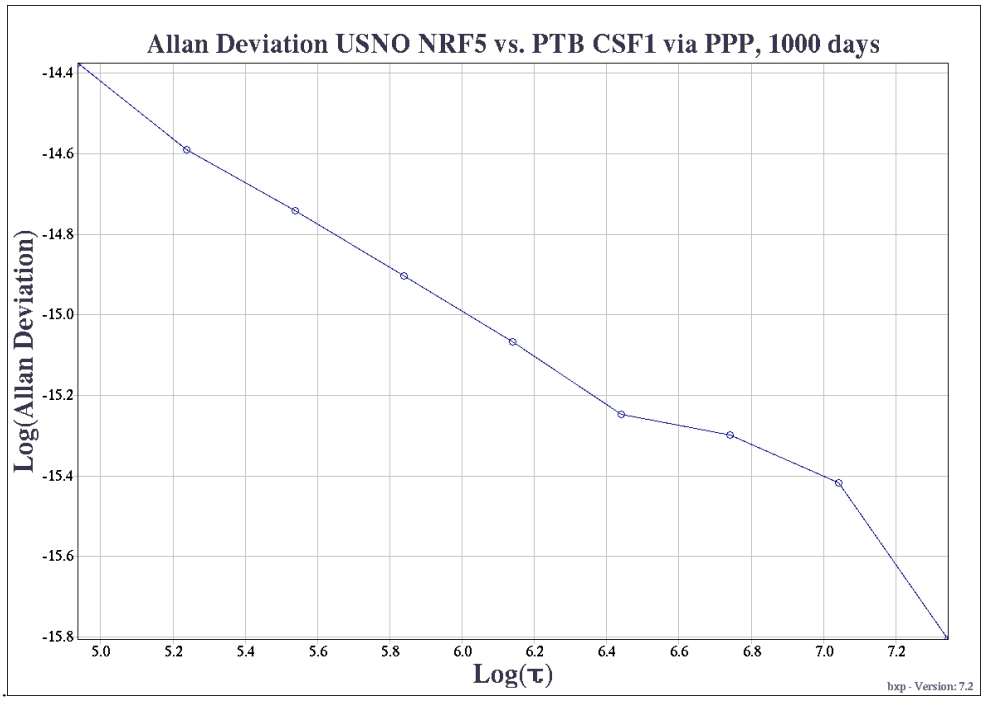

Figure 2 Allan Deviation of USNO-PTB fountains, in the presence of time-transfer noise. Since data from the entire data set are included, the curve is not sensitive to recent improvements.

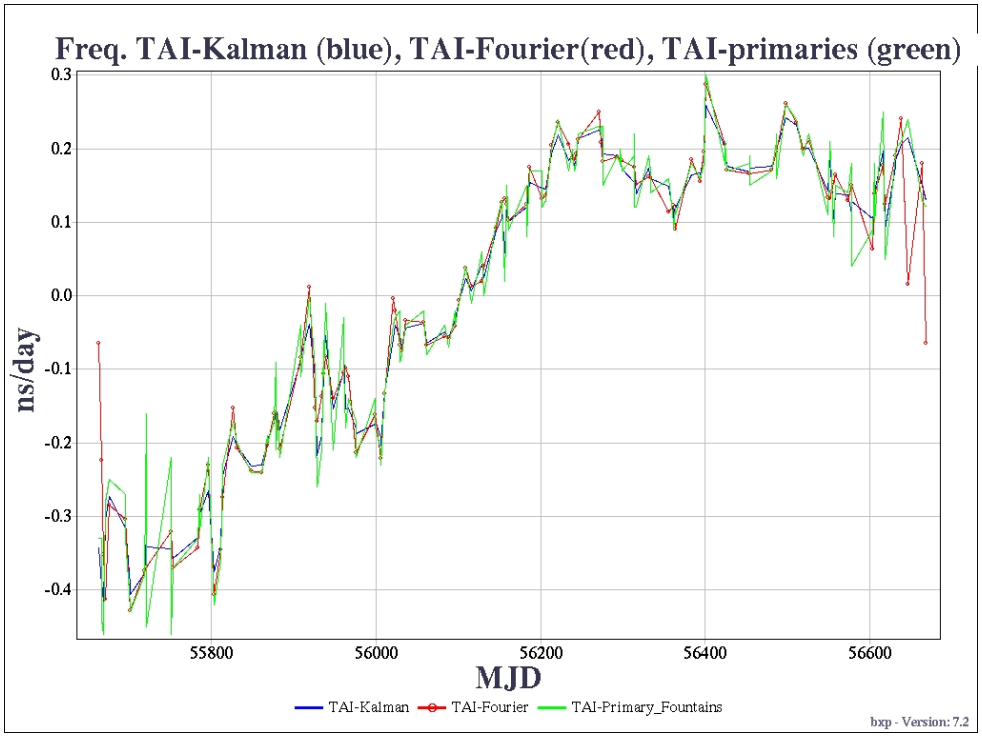

Figure 3. Fits to TAI-Primary Fountain data using Kalman Filter (blue) and Fourier solution (red), which is the only curve with individual point markers. The green curve displays the data fitted to.

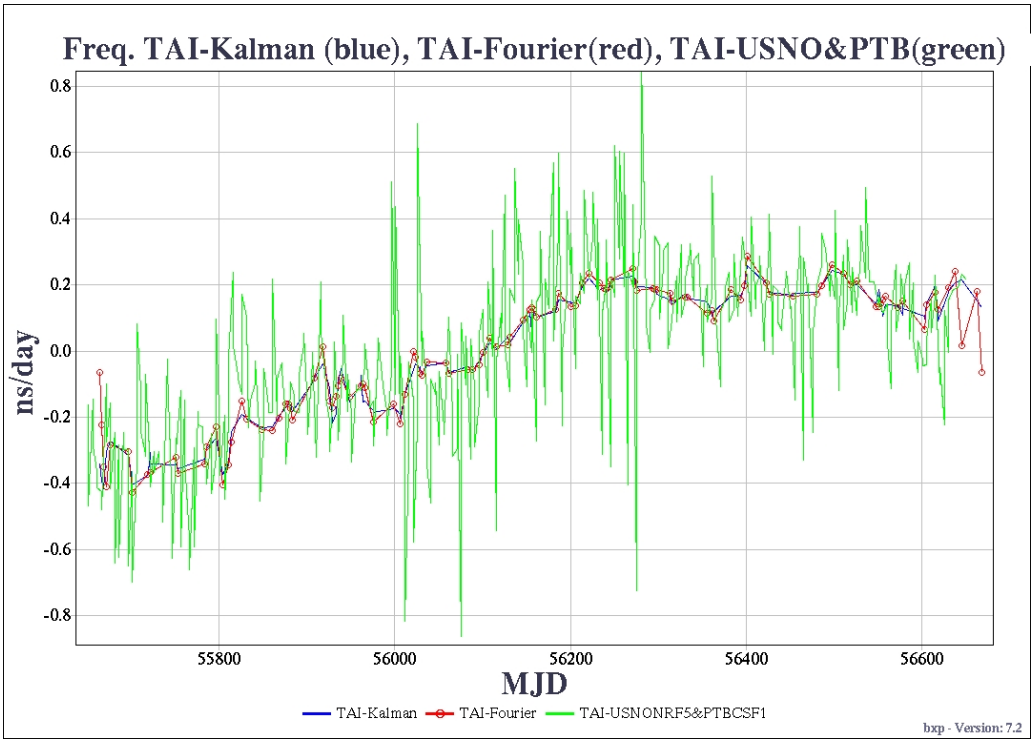

Figure 3. Fits to TAI-primary fountain data using a Kalman filter (blue), and a Fourier solution (red), which is the only curve with individual point markers. The green curve shows an unsmoothed combination of TAI-NRF5 and TAI-PTBCSF1.

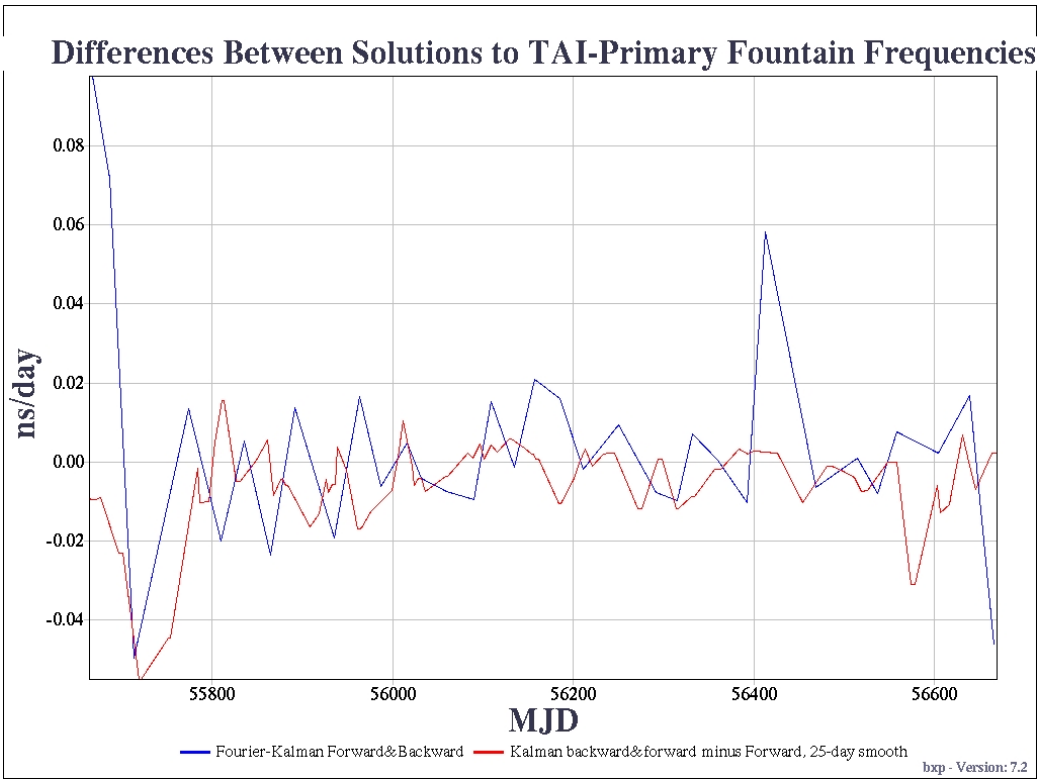

Figure 5. The differences between the Kalman forward+backward solution and the Fourier solution (blue), and the difference between the Kalman forward+backward solution and the forward-only Kalman filter (red). The edge effect in the Fourier solution is not understood as of this submission.