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THE DESIGN OF KALMAN SMOOTHERS FOR GLOBAL POSITIONING DATA

M. A. Weiss
National Bureau of Standards
Time and Frequency Division
Boulder, CO 80303

Abstract

Measurements of clocks aboard Global Positioning System (GPS) satellites as well as GPS system time are made many times per day at time standards laboratories around the world according to a tracking schedule issued by the Bureau International des Poids et Mesures (International Bureau of Weights and Measures). We compute Kalman smoothed estimates of clocks in the standards labs to define a global time base, then compute Kalman smoothed estimates of GPS clocks against this time base. Biases in measurements repeated once per sidereal day produce apparent diurnal effects in the data. A composite time and frequency Kalman estimator is used here. This allows updates of clocks at time intervals less than one day while aliasing diurnal variations.

Summary

The measurements of international time standards labs against Global Positioning System (GPS) clocks provide many opportunities for interesting studies. First we can compare the reference clocks themselves. Second we can study the GPS. Since the reference clocks are extremely stable their differences can be known to under ten nanoseconds with measurements only a few times per day. Since the labs are on the same tracking schedule, satellites are tracked simultaneously at several locations, and these tracks are repeated each day when the satellites are nominally in the same location relative to the rotating earth. It has been shown previously that these data can be used to separate variances of various noise terms.[1] Here we use these variances to set noise parameters in Kalman smoothers to obtain linear estimates of clocks. We make two different kinds of estimates: (1) estimates of the clocks at the standards labs against either a pivot clock or against the algorithm itself; and (2) estimates of clocks aboard GPS satellites and of GPS system time. The first type of estimate is used to define a global time base to measure the satellites against as they circle the globe. The second type of estimate is smoothed from these measurements of the satellites against the global time standard.

We use two types of Kalman smoothers: a time Kalman smoother, and a mixed time-and-frequency Kalman smoother. The time smoother is used initially as a standard technique of obtaining optimal estimates of clock states in the presence of white phase noise. From this we discover significant biases in the data. The mixed time-and-frequency smoother allows us to alias the biases while still using measurements at time intervals of less than one day.

The estimates of time standards labs against each other present a method for time transfer at accuracies of the order of several nano-seconds. In addition, these measurements are available several times per day. We present a new time scale algorithm by estimating the time standards labs against the scale. Figure 1 shows the fractional frequency stability of this algorithm from generated data some of whose variances are shown in figure 2. Figure 3 shows the performance of UTC(NBS) against the algorithm. The output of the algorithm when operating on data from time standards labs is apparently better than the best contributing clocks.

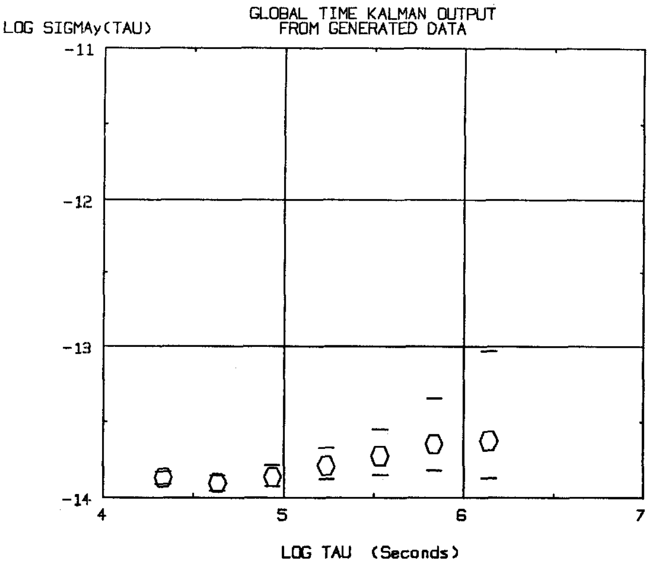

Figure 1 shows the fractional frequency stability of the time scale data from the algorithm of the time Kalman smoother operating on generated data.

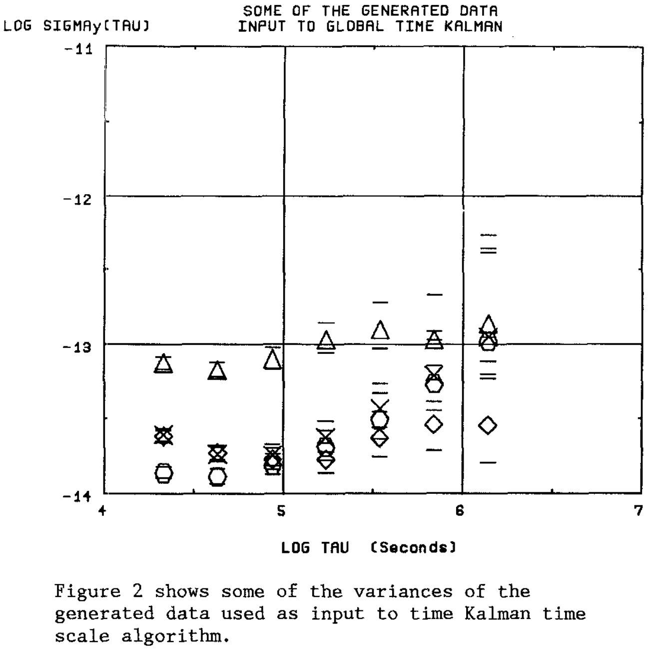

Figure 2 shows some of the variances of the generated data used as input to time Kalman time scale algorithm.

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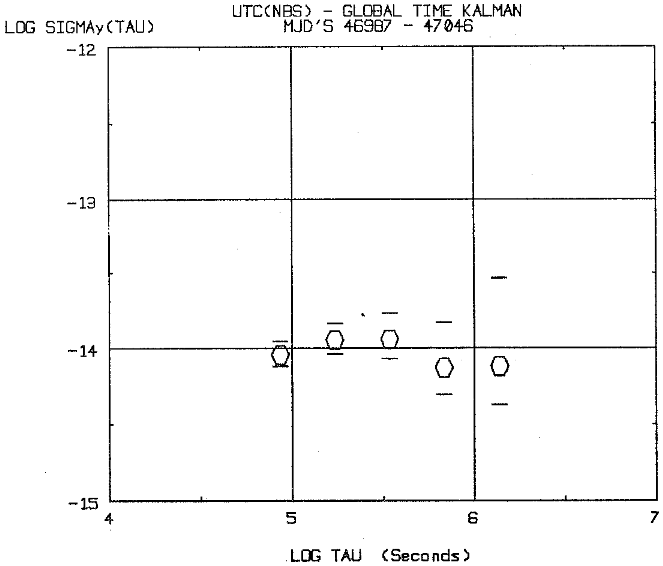

Figure 3 shows the performance of UTC(NBS) against the time Kalman time scale algorithm.

Estimates of GPS system time minus Global Time are shown in figure 4. An apparent diurnal variation appears due to biases in measurements which repeat each sidereal day. A mixed time-and-frequency Kalman smoother which updates frequency at each measurement, and updates time once per day, is expected to avoid the problem of biases, by aliasing them. Figure 5 shows the output of the time-and-frequency smoother operating on the same data in figure 4. The diurnal variations due to biases seem to be gone. This technique is explored in the paper.

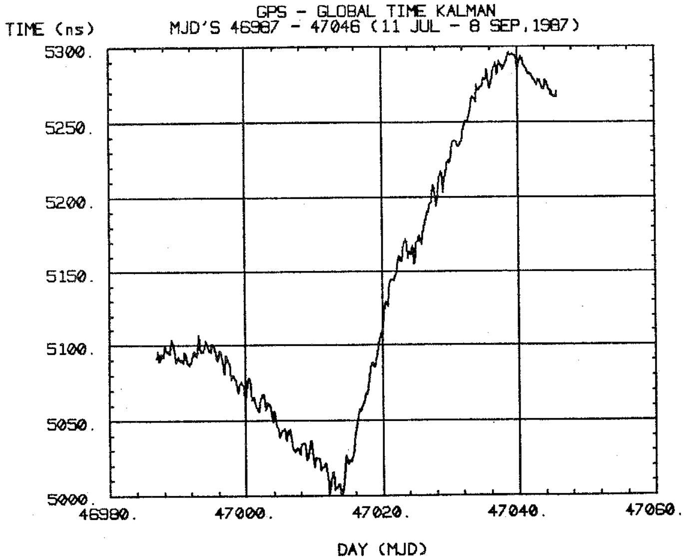

Figure 4 gives time Kalman estimates of GPS system time minus Global Time. An apparent diurnal variation appears due to biases in measurements which repeat each sidereal day.

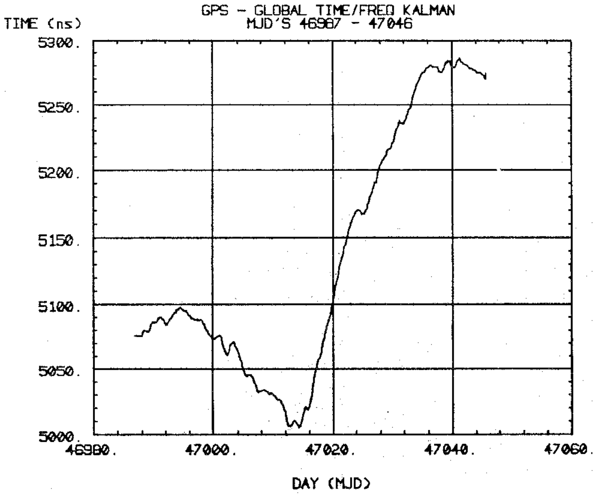

Figure 5 shows the output of the mixed time-and-frequency Kalman smoother which updates frequency at each measurement, and updates time once per day operating on the same data in figure 4. The diurnal variations due to biases seem to be gone.

References

[1] "Using Multiple Reference Stations to Separate the Variances of Noise Components in the Global Positioning System," M.A. Weiss and D.W. Allan, 40th Annual Frequency Control Symposium, Philadelphia, PA, 1986, p. 394. (Available from Institute of Electrical & Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854).