A Time Scale Algorithm for Post-Processing: AT1 Plus Frequency Variance

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Abstract

A post-processed scale can take advantage of better characterization of the clocks in the time scale ensemble and improved capability for frequency step detection. We present here a particular time scale algorithm run in post-processed mode and use real and simulated data to show how it compares with AT1 alone.

Summary

Post-process time scale algorithms are useful in applications where the output of a time scale is not needed in real time. An important example of this type of application is the study of the millisecond pulsar, PSR 1937+21 [1]. Several years of measurements of the pulses of this object with existing systems reveal that its stability rivals those of the world's best atomic clocks and time scales at integration times of one year. Another application of a post-processed time scale is the extrapolation of an evaluation of a clock ensemble against a primary frequency reference. In this case, we want to know how the frequencies of clocks in the ensemble have changed relative to a stable reference over a period of time in the past. Applications such as these benefit from the use of a post-processed time scale if it improves long term performance. Characterizing the long term behavior of clocks for a given integration time requires a time interval several times longer than that integration time. A post-processed scale can take advantage of these improved characterizations of clocks in the scale. Another advantage of post-processing is an improved capability for frequency step detection. A frequency step in a clock cannot be detected and characterized until some time after its occurrence, depending on the size of the step.

Previous post-process time scales include work by Allan on long term stability [2], and the development of Terrestrial Time BIPM by Guinot [3,4]. The post-processed scale we are studying at NIST is a continuation of our development of a new time scale, AT1 plus frequency variance [4]. This scale is essentially the AT1 time scale (run at NIST since 1968) with the addition of an estimate of each clock's frequency state variance from a modified Kalman formalism. Using AT1 plus variance, we have developed a technique for automatic frequency step detection which can be used in a real-time time scale algorithm. For the post-processed scale we run the AT1-plus-variance scale with automatic frequency step detection over a fixed time interval of data with a three-pass (chronologically forward-backward-forward) smoothing algorithm. On the third pass, we combine the forward and backward estimates of frequency for each clock at a given time using the reciprocal of the variance as the weight. In this way we obtain an optimally smoothed estimate of the frequency offset of each clock from the generated ensemble frequency.

This technique for estimating the frequency offset of each clock from the scale also improves frequency step detection. Frequency steps are dealt with in the AT1-plus-variance algorithm by removing a clock from the scale and increasing its variance from the time of the detected step until the scale has a chance to learn the new frequency. If this is done independently by both forward and backward passes, then, for example when a frequency step occurs, during the period when a clock has been removed from the forward algorithm, the backward algorithm will not yet have encountered the step. Therefore, just before or just after a frequency step, one of the algorithms, either the first forward one or the backward one, will provide a good estimate of the frequency of that clock.

We complete the post-processed scale by estimating the time of each clock in the scale using the part of AT1 which does this, but using the post-processed frequency estimates instead of estimating frequency. This last step is actually combined with the third pass through the data where we combine the forward and backward frequency estimates of the algorithm. Results from applications of this algorithm to simulated and real clocks are presented.

References

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