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Simulation Model for the Realisation of the UTC(SCL)

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Abstract

This paper describes the simulation model developed at the Standards and Calibration Laboratory (SCL) to refine the realisation of the UTC(SCL). Time-difference between the UTC(SCL) and other time data sets, including two caesium atomic clocks, a hydrogen maser clock and the GPS time data, are used in the model to adjust the frequency steering parameters for the realisation of the UTC(SCL) through simulation, thereby improving its accuracy and stability.

1. Introduction

The generation of a precise and reliable time scale relies on an appropriate equipment setup and a well-designed algorithm [1]. As illustrated in Figure 1, the SCL uses a master caesium frequency standard with a microphase stepper to steer the reference frequency signal of a time scale generator to realise the UTC(SCL). An in-house developed frequency steering correction algorithm is used to adjust the frequency steering of the microphase stepper by analysing the time-difference data between the UTC(SCL) and the laboratory's caesium atomic clocks, a hydrogen maser clock, the GPS time data, the UTCr data and the UTC data. Linear regression method [2] is employed in the algorithm to model mathematical expressions based on the time-difference data, and to facilitate the calculation of the frequency steering correction setting for the microphase stepper [3]. The time-difference between the UTC(SCL) and the UTC is continuously assessed, and the algorithm estimates the steering correction to gradually reduce the time-difference to a target range. When the time-difference is within the target range, the algorithm estimates the correction to compensate for the daily drift of the UTC(SCL). A simulation model is developed to project the future trend of the UTC(SCL), which facilitates the evaluation of the adjustment parameters associated with frequency steering. This also enables the optimisation of the algorithm in order to achieve the synchronisation between the UTC(SCL) and the UTC, while minimising frequency variation.

2. Time-Difference Simulation Model

The trend of the UTC(SCL) is analysed by comparing its difference from the laboratory's caesium and hydrogen maser clocks, GPS, UTCr and UTC time data. Time-difference between each time data source and the UTC(SCL) data were

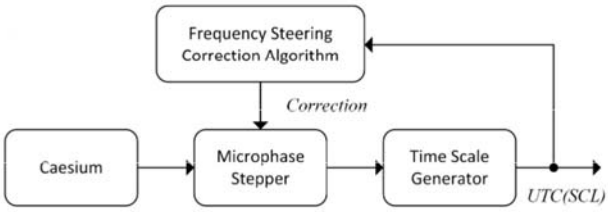

Figure 1. Simplified block diagram of the SCL time scale system.

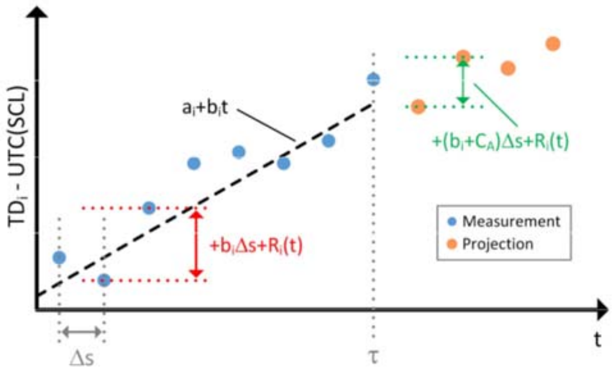

Figure 2. Illustration of the time-difference features.

analysed statistically by using the linear regression method. The trends of the time-difference can be modelled as eq. (1), which predicts the change in time-difference per elapsed time step of Δs as $b_i \Delta s$.

$$TD_i - UTC(SCL) = a_i + b_i t = D_i(t) \tag{1}$$

where TD_i is the time data, a_i and b_i are coefficients of the linear model, t is the elapsed time, $D_i(t)$ is the time-difference at that elapsed time, and subscript i represents different time data sources. In practice, the variations of time-difference at each elapsed time step could be attributed to various factors, including variations in ambient conditions and stability and drift of equipment. For each time data source, SCL expresses the variations as uniformly distributed random functions $R_i(t)$. An example of time-difference features is illustrated in Figure 2. Assume that the time-difference measurement data is collected up to elapsed time τ, the time-difference at each projected time steps can be estimated using a linear extrapolation model, together with the frequency steering correction and the random functions $R_i(t)$. The projected time-difference at time step Δs can be modelled by eq. (2).

$$D_i(\tau + \Delta s) = D_i(\tau) + (b_i + C_A)\Delta s + R_i(\tau) \qquad (2)$$

where C_A is the projected frequency steering correction after time τ. The time-difference of each time data source can be estimated by an individual modelling equation. These projected time-difference data sets are then combined to simulate the trend of the UTC(SCL). The UTC(SCL) simulation flow diagram is shown in Figure 3. Sufficiently long time-difference data measured by various time data sources were used to establish the initial trend and variation characteristics of the UTC(SCL). Time-difference equations, including: the GPS time, the two caesium atomic clocks, and the hydrogen maser clock, were modelled and used to calculate their time-difference from the UTC(SCL) for each elapsed time step of Δs. Using the traceable characteristics of GPS time to the UTCr and the UTC [4][5], the time-difference between the UTC(SCL) and the GPS time is used as the reference to estimate the time-difference between the UTC(SCL) and the UTCr, and between the UTC(SCL) and the UTCr at that elapsed time along with the associated uncertainties. The calculation is performed recursively for projected time steps, enabling the simulation of the future trend of the UTC(SCL).

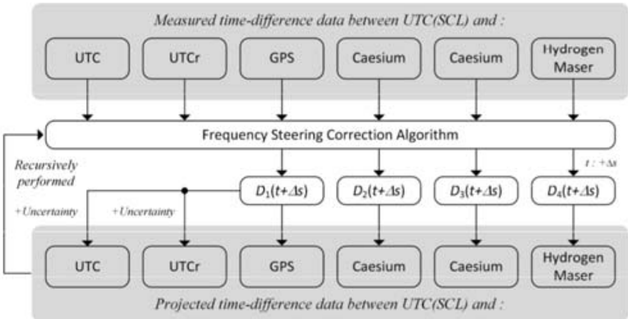

Figure 3. Simulation flow diagram of the UTC(SCL) realisation.

3. Simulation Analysis

With the simulation approach, the parameters of the frequency steering correction algorithm presented in [3] were optimised to refine the accuracy and stability on the time scale. Figure 4 shows the simulated time-difference between the UTC and the UTC(SCL) from MJD 60450 and over the next 200 days. Appropriate scaling in the random functions were included in the simulation so that the UTC(SCL) is projected to a predictive range. The actual time-difference during this period was compared and consistent with the projected range. Relative frequency of the laboratory's reference is shown in Figure 5, which the actual data was also well consistent with its projected range. The simulation could effectively improve the model parameters, including the correction limit and frequency offset limit, in the model of the UTC(SCL), and could improve the overall performance of the realised time scale and reference frequency.

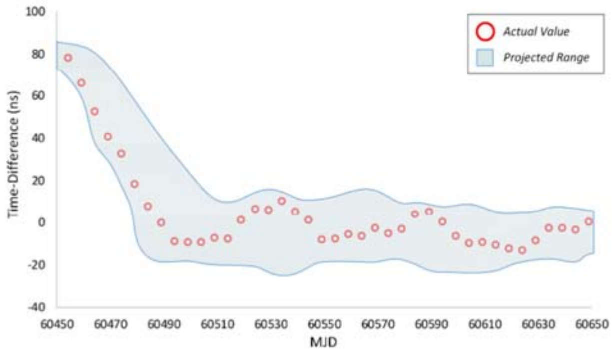

Figure 4. Time-difference between the UTC and the UTC(SCL).

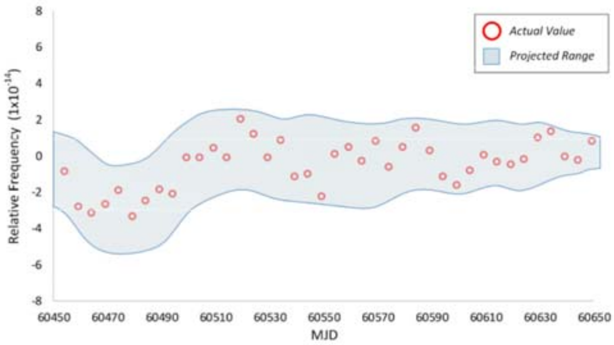

Figure 5. Relative frequency of the laboratory's reference in 5 days average

4. Conclusion

The SCL has developed a simulation model to predict the trend of the UTC(SCL), which could help fine tuning the parameters of the frequency correction algorithm to improve the accuracy and stability of the UTC(SCL). This would enable the laboratory's reference equipment to establish their traceability to the clock with better reference frequencies.

References

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