Introduction of GNSS Up-Sampled All-in-View Time Transfers

Wen-Hung Tseng, Shinn-Yan Lin
National Standard Time and Frequency Laboratory
Telecommunication Laboratories, Chunghwa Telecom Co., Ltd.
Taoyuan City, Taiwan
whtseng@cht.com.tw

***Summary*—The up-sampled all-in-view (UAV) method is a new technique being developed to improve the precision of long-distance GPS P3 code time transfer, specifically for the time link between the Telecommunication Laboratories (TL) in Taiwan and the Physikalisch-Technische Bundesanstalt (PTB) in Germany. By combining up-sampled data and original observations based on their respective uncertainty estimations, the precision of the UAV results can be compared with that of precise point positioning (PPP) results. The modified Allan deviation (MDEV) of TL-PTB UAV results at a 960-s averaging time reaches 9×10^{-15}. Moreover, the long-term behavior of the UAV remains consistent with conventional GPS all-in-view (AV) results. Improving the precision of code measurements could enhance our understanding of their behavior and potentially reduce the averaging time required for GNSS time transfer calibration.**

Keywords—GNSS; code; time transfer; All-in-view; PPP; uncertainty

I. Introduction

GNSS code measurements have good accuracy but lack sufficient precision for the time transfer of modern high-performance clocks. As a result, most code-only GPS P3 links have been replaced by the precise point positioning (PPP) links for the TAI computation [1]. However, the calibration of GNSS timing receivers still relies on code measurements [2], and it typically takes several days to weeks to achieve an uncertainty level of 1 ns. Therefore, it would be beneficial to improve the precision of code measurements to shorter the period of time collecting and processing data.

In 2021, we proposed the up-sampled common view (UCV) method to reduce latency and improve the precision of P3-code based GPS time transfer in long baselines [3]. The UCV method generates time transfer results using daily CGGTTS files [4], without the need for data from an agency of the International GNSS Service (IGS). However, if the goal is to study the long-term performance of the clocks rather than to obtain rapid results, using IGS products in the UCV solution can further reduce biases of satellite clock and ephemeris broadcasts [3][5]. This can improve the accuracy of the time transfer results.

The original UCV solution is effective at smoothing out short-term variations in time transfer data, but this can also mask the true behavior of the clocks and cause a slower response to sudden time changes or time steps. Our research has shown that this method is effective for H-maser links, but provides less improvement for links based on Cs clocks [6]. This is because the error in UCV's interpolation is primarily attributed to the greater prediction uncertainty of Cs clocks, and this error is much smaller in the case of H-maser links. The up-sampling method utilizes linear interpolation to predict data values during the gaps between two available GPS observation sets, which occur over a period of one sidereal day when the same satellite appears in the same part of the sky. The main objective of this method is to increase the volume of available data by filling in gaps in the data. However, the accuracy of the interpolated data may be compromised by prediction errors. A more effective approach to improving accuracy is to weight the results based on the estimated uncertainty of the data.

The common-view (CV) method involves computing the time difference between two labs for each satellite at a specific epoch, and then averaging the data from all GPS satellites. On the other hand, the all-in-view (AV) method involves separately averaging the data from the entire group of GPS satellites in view at each site, with respect to a common reference IGS timescale (IGST), before calculating the time difference between the two labs [7]. By conducting a closure loop analysis to verify the time difference results of any three laboratories, the utilization of the all-in-view process guarantees the constancy of their closure sums. Therefore, in the ensuing study, we will be using the AV method, which we will refer to as the up-sampled all-in-view (UAV) method.

In this study, we introduce an updated version of the GPS up-sampling technique that incorporates existing GPS P3 data of code observation and up-sampling data predicted based on atomic clock characteristics. Our approach involves integrating observation and up-sampling data using advanced weighting algorithms to enhance the precision of time comparison data while preserving the most significant features of the code measurements.

II. Methods and Results

The objective of this study is to enhance the precision of GPS P3 code time transfer. Our proposed technology incorporates up-sampling, which involves a resampling and self-expansion process. This approach enables us to refine the precision of the original data obtained from the CGGTTS files, which have been corrected by the IGS products.

Figure 1 illustrates the GPS PRN31 data of TL-IGST, which exhibits unequal spacing between observed data points. By resampling the data and calculating the mean, we can generate a data set with reduced noise due to the averaging process, resulting in one data point per sidereal day. We then perform self-expansion by utilizing linear interpolation to predict the values of data in the gaps between two mean points. These predicted values are referred to as up-sampled data. Figure 2 depicts the up-sampled data achieved through linear interpolation to predict the values of data in the gaps between two mean points.

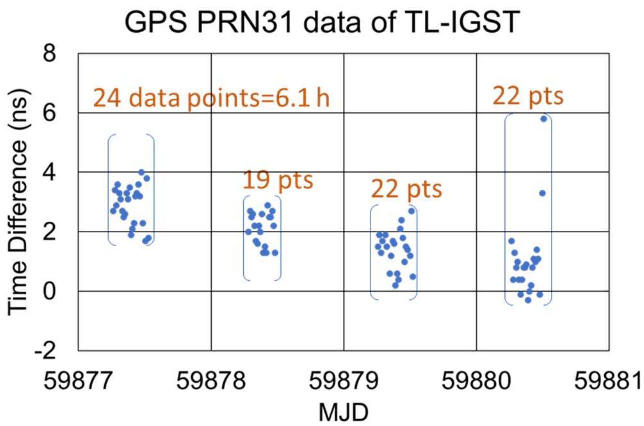

Fig. 1. Time difference of GPS PRN31 data of TL. The original data were obtained from CGGTTS files corrected by IGS products (2022/11)

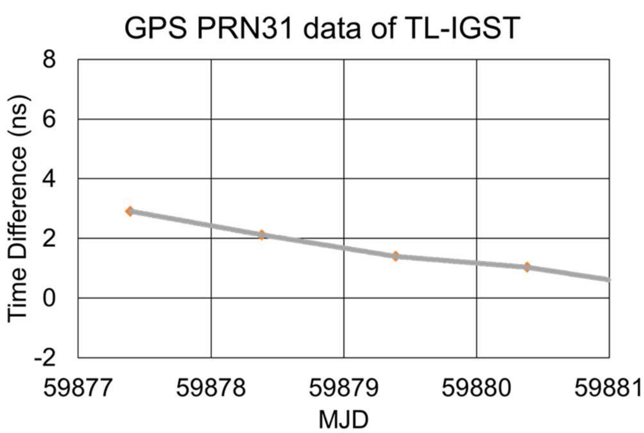

Fig. 2. Time difference of GPS PRN31 data of TL. The up-sampled data were obtained by interpolation in the gaps between two mean points.

As the interpolated data are too smooth and lack short-term variations, they may not respond well to sudden time steps. To overcome this issue, we combine the interpolated data with the original data by assigning weights based on their uncertainty estimation. Accurately estimating the uncertainty of the data is crucial to the success of this method. We are currently preparing a full journal paper to discuss the uncertainty estimation in detail. Our research has shown that this method is particularly effective for H-maser links, as H-maser exhibits minimal prediction uncertainty for interpolation within a single day. However, we believe that this method can be applied to other types of links as well, and further research is needed to explore its potential in different scenarios.

In this study, we adopt a relatively straightforward approach to estimate the uncertainty of the mean data point. Specifically, we calculate the mean and standard deviation of each original continuous dataset. If the dataset is sufficiently large, the estimation of standard deviation is typically accurate. However, if the dataset is small (consisting of only a few data points), the resulting deviation may be too small. In such cases, we assign a limit uncertainty to the mean value (e.g., 0.5 ns). Next, we generate the up-sampled data by interpolation and estimate their uncertainties. The uncertainty, referred to as type-A (one-sigma) value, is determined based on the prediction error [8-9] and the standard deviation of the raw dataset.

To combine the observation and up-sampled data, we employed a weighted average approach based on their corresponding uncertainties. Subsequently, we calculated the uncertainties of the combined data. Figure 3 illustrates the flow chart of the UAV process, which differs from the UCV process in terms of data processing order. Specifically, in the UAV process, weighting is performed prior to differential calculation to better preserve information during data processing. Figure 4 displays the UAV results of UTC(TL)-IGST and UTC(PTB)-IGST time differences obtained through a combination of observation and up-sampled data.

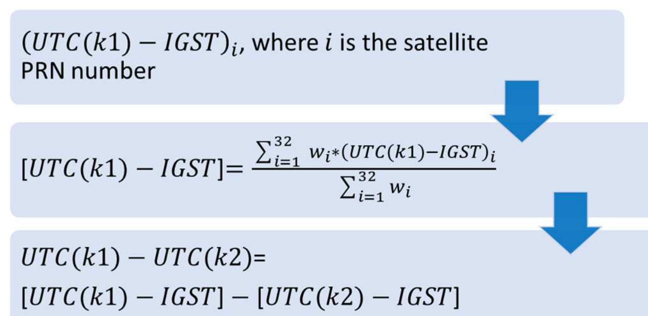

Fig. 3. Flow chart of Upsampled All-in-view (UAV).

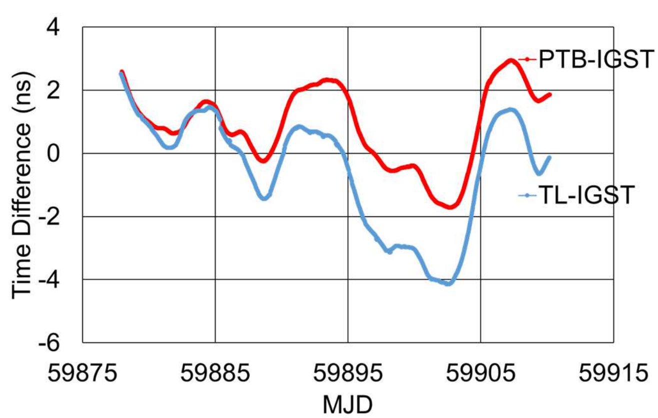

Fig. 4. UAV results of TL-IGST and PTB-IGST time differences.

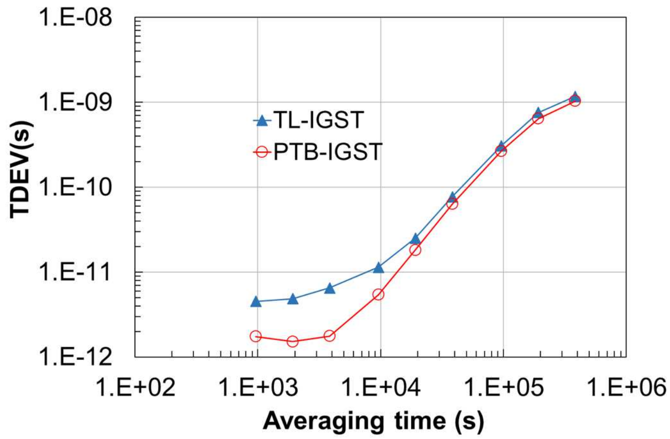

Fig. 5. Time deviation (TDEV) of the UTC(TL)-IGST and UTC(PTB)-IGST UAV results.

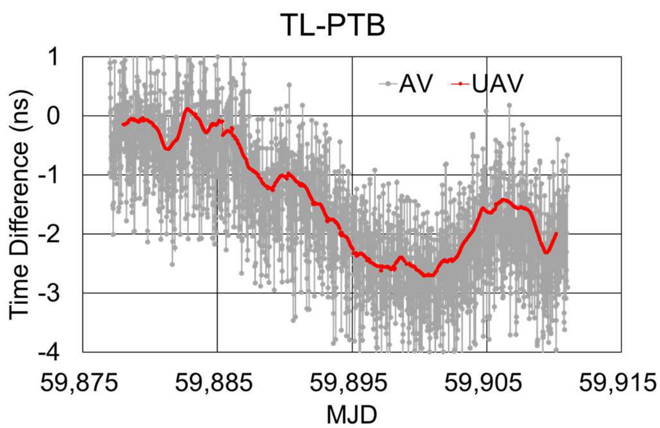

Fig. 6. Time differences for the TL-PTB link obtained through UAV (red line) and conventional AV (gray line) results.

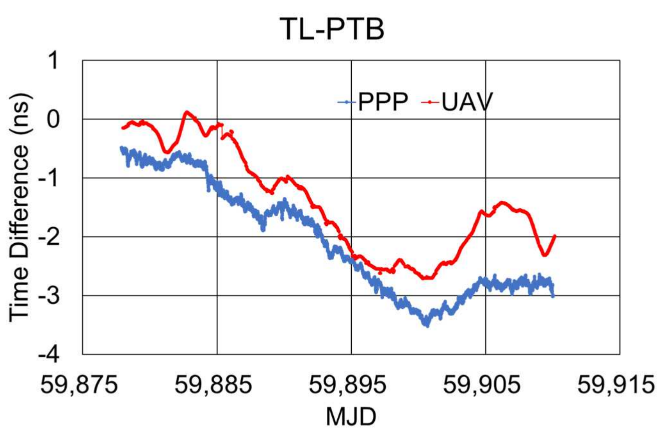

Fig. 7. Time differences for the TL-PTB link obtained through UAV (red line) and PPP (blue line) results.

Figure 5 shows the time deviation (TDEV) of these results. In the short-term (less than 1 h), their TDEVs are only a few picoseconds, comparable to those of two H-masers located in the same place and directly measured by a time interval counter. Finally, we are able to calculate the time difference between the two laboratories. Figure 6 illustrates the results of the TL-PTB link obtained through UAV and conventional AV methods for comparison. The UAV results exhibit a much clearer curve than the conventional AV results. Figure 7 compares the UAV and PPP results of the TL-PTB link. While the long-term trend of the UAV is similar to that of the PPP, the fluctuations of the UAV do not entirely match those of the PPP.

Figure 8 displays the modified Allan deviation (MDEV) of the TL-PTB AV, PPP, and UAV results. At short-term averaging times, the deviations of the UAV are approximately one percent of those of the conventional AV results. The deviations of UAV and AV remain consistent above one-day averaging times. The UAV method appears to be more stable than PPP for averaging times of less than 2×10^4 seconds. Notably, the MDEV of the UAV at a 960-s averaging time reaches 9×10^{-15}.

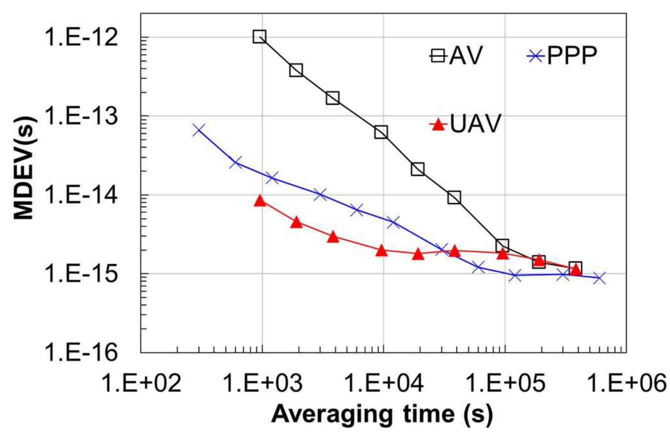

Fig. 8. Modified Allan deviation (MDEV) of TL-PTB AV, PPP, and UAV results: Conventional AV (black square), UAV (red solid triangle), and PPP (blue x cross) data.

III. Conclusions

In this study, we have proposed a new version of the GPS up-sampling technique, the UAV method, which utilizes existing GPS P3 data of code observation and up-sampling data predicted based on atomic clock characteristics. By integrating the up-sampling data and original observation using advanced uncertainty estimation, the precision of the UAV results can be compared with the PPP results, and the long-term behavior of the UAV is consistent with conventional AV results.

Improving the precision of code measurements would enable a better understanding of their behavior and could potentially reduce the time required for data collection and processing. This could have significant benefits in various applications, including time transfer, clock synchronization, and the calibration of GNSS timing receivers.

Acknowledgment

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REFERENCES

[1] G. Petit and Z. Jiang, "Precise point positioning for TAI computation", Int J Navig Obs 2008:1–8.

[2] P. Defraigne, J. Achkar, M. J. Coleman, M. Gertsvolf, R. Ichikawa, J. Levine, P. Uhrich, P. Whibberley, M. Wouters and A. Bauch, "Achieving traceability to UTC through GNSS measurements", Metrologia, vol. 59, 2022. 064001 (12pp).

[3] W.-H. Tseng and S.-Y. Lin, "Improving long-baseline rapid GPS time transfers by a modified common-view method", GPS Solutions, vol. 25, no. 2, pp. 1–10, 2021.

[4] P. Defraigne and G. Petit, "CGGTTS-Version 2E: an extended standard for GNSS time transfer", Metrologia, vol. 52, G1, 2015.

[5] W.-H. Tseng, "Comparison of GNSS All-in-View (AV) and Upsampled Common-View (UCV) time transfers", 2021 Joint Conference of the European Frequency and Time Forum and IEEE International Frequency Control Symposium (EFTF/IFCS), Gainesville, FL, USA, 2021, pp. 1-3.

[6] The study has not been published yet.

[7] G. Petit and Z. Jiang, "GPS all-in-view time transfer for TAI computation", Metrologia, vol. 45, no. 1, pp. 35–45, 2007.

[8] W.-H. Tseng and S.-Y. Lin, "Uncertainty analysis of interpolation prediction for the blind period: using the portable clock measurement as an example", Proceedings of the 53rd Annual Precise Time and Time Interval Systems and Applications Meeting, Jan. 2022, pp. 108-118.

[9] D. W. Allan, "Time and Frequency (Time-Domain) Characterization, Estimation, and Prediction of Precision Clocks and Oscillators," in IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, vol. 34, no. 6, pp. 647-654, Nov. 1987