XX IMEKO World Congress
Metrology for Green Growth
September 9−14, 2012, Busan, Republic of Korea

GEODETIC CLASS GPS RECEIVER AS A STANDARD FOR TIME-CRITICAL APPLICATIONS

Vukan Ogrizović[1], Jadranka Marendić[2], Snežana Renovica[3], Siniša Delčev[4], Jelena Gučević[5]

[1]University of Belgrade, Faculty of Civil Engineering, Department of Geodesy and Geoinformatics, Bulevar kralja Aleksandra 73, 11000 Belgrade, Serbia, vukan@grf.bg.ac.rs
[2]Directorate of Measures and Precious Metals, Mike Alasa 14, 11000 Belgrade, Serbia, marendic@dmdm.rs
[3]Directorate of Measures and Precious Metals, Mike Alasa 14, 11000 Belgrade, Serbia, renovica@dmdm.rs
[4]University of Belgrade, Faculty of Civil Engineering, Department of Geodesy and Geoinformatics, Bulevar kralja Aleksandra 73, 11000 Belgrade, Serbia, delcev@grf.bg.ac.rs
[5]University of Belgrade, Faculty of Civil Engineering, Department of Geodesy and Geoinformatics, Bulevar kralja Aleksandra 73, 11000 Belgrade, Serbia, jgucevic@grf.bg.ac.rs

Abstract: GPS receivers are often used in time-keeping applications, due to their availability, low price and high accuracy. We made a research in order to test the capability of the GPS receiver to deliver a time-keeping accuracy needed for the time-critical applications, such as astrometry measurements, when a microsecond or even better level of accuracy is needed in real-time. We tested a geodetic class GPS receiver against a rubidium standard, over a 24 hours period. In the overall view, we obtained the accuracy that corresponds to the nominal values. However, we experienced outliers with the certain regularity that we could not explain with cycle-slips or the experiment set-up. Therefore, we are suggesting a longer experiment, to include other possible reasons for those outliers.

Keywords: .GPS, PPS, time-keeping, Allan variance

INTRODUCTION

Distributed industrial and technological systems request precise time synchronization between their sectors. Devices connected to each other by a communication link have to share the same time system in order to complete their tasks [8]. The designers of the distributed systems recognize GPS as a suitable tool for the time synchronization [5]. The components of the distributed system can easily use the readily available GPS time standard, wherever they are located.

Computers in a local or a wide-area network .synchronize their times using Network Time Protocol (NTP). In such client-server configuration, time matching between the workstations should be much under a second.

The results of an experiment with five GPS receivers, connected to the same antenna, delivered the accuracy better than 50 ns for all the clocks [2]. Here, direct measuring of 1PPS was used, instead of the transmission of the clock corrections via NTP.

An example of a high-precision time-keeping is monitoring of bridge deviations due to a heavy load. The surveyors mount the GPS receivers to characteristic points on the bridge. The receivers collect data for a long period under different loadings. The relative accuracy of baseline vectors between the receivers depends on a lot of factors that decrease the accuracy of the vectors. Since the field crew do not have any impact on ambient conditions, the accuracy can be increased only by adapting the measuring method. Time synchronization is a tool for better resolving the pseudo-ranges and phase differences, which eventually has a positive impact to the quality of the estimated baselines.

Accurate time is necessary for the astrometry applications, like determination of Earth's orientation [14]. Also, due to Earth’s rotation, the positions of observed radio-sources or stars, depending on the measuring method, change constantly. The epoch of the observation with the error of 100 ms corresponds (depending on the measuring method) with tens of meters in the position at the Earth’s surface.

In the astrometry applications, the accuracy in the order of microseconds (or better) is requested. The GPS receivers manufactured for timing applications or geodetic class GPS receivers provide the 1 Pulse Per Second (1PPS) events with the accuracy of up to 10 ns, according to the manufacturers' specification. Here we performed a 24-hours test of such GPS receiver, comparing its 1PPS against a Rubidium standard. The test should show whether the GPS receiver can provide reliable, consistent and accurate time signals over a 24-hour period.

Many other applications need precise time-keeping: event reconstruction, synchrophasors, system time and frequency deviation, multi-rate billing, power quality incentives, time tagging recorded data, wide area measurements systems, travelling-wave fault detection, end-to-end relay testing [7], and even electronic betting systems [10].

2. BACKGROUND AND METHODS

2.1. Time-keeping and transmission of time

Time marks are transferred to users by many means, including terrestrial or satellite systems [13]. The GPS receivers usually transfer their time via an NTP network, serving as a stratum 1. Depending on the configuration, the GPS receiver can work as a node in the network, delivering the time signals using the TCP/IP protocol, or directly via a serial or a USB port. Both methods assume the 24/7 configuration, with occasional corrections of the clock in the computers being synchronized.

Several manufacturers of the GPS equipment offer a special class of the GPS receivers capable of delivering 1PPS via a BNC output, disciplining a computer clock applied in the specific timing application. Those 1PPS outputs are often steered using the receiver's GPS data, and do not represent the 1PPS output of the internal clock [16]. The application is not ready at glance, but rather a user writes a custom low-level routine, written in the low-level C or, even, assembler [15].

The features of the operating system influence the latencies appearing during the transfer of time signals from the source of 1PPS to the computer. For that reason, such time-keeping routine often runs under a Real-Time Operating System (RTOS). The RTOS treats software and hardware interrupts in a special way, minimizing the latencies. Synchronization by catching the PPS ticks with interrupts implies the permanent synchronization with the minimal latencies [11].

All methods used for the time-keeping by the GPS receivers share the same issue. The configuration requires a minimum of 15 minutes after the start of the synchronization to adjust the computer clocks to desired accuracy.

2.2. Resolving cycle slips

Cycle slips represent sudden jumps in GPS integrated phase measurements. When the cycle slip occurs, a new unknown appears in the mathematical model of an autonomous or relative solution. Increasing the number of unknowns degrades the internal reliability of the adjustment solution. Because of that, an extreme attention is paid to the cycle-slips resolving.

Here we applied the bias optimizing method [3]. If b_1 and b_2 are frequency biases for GPS frequencies L1 and L2, respectively, after the cycle slips in the amounts Δn_1 and Δn_2, new biases become b'_1 and b'_2, which can be written as:

$$\left(\Delta n_1, \Delta n_2\right) = \left(b'_1 - b_1, b'_2 - b_2\right) \tag{1}$$

For double-frequency GPS receivers, a wide-lane linear phase combination Φ_δ of carrier-phase data on frequencies Φ_1 and Φ_2 is created:

$$\Phi_\delta \equiv \left(\Phi_1 - \Phi_2\right) \tag{2}$$

which, after the development given in [4], yields to the bias of the wide-lane combination:

$$b_\delta = \frac{1}{\lambda_\delta}\left(L_\delta - P_\delta\right) \tag{3}$$

with λ_δ - wavelength, L_δ - carrier-phase data expressed in cycles, and P_δ - code pseudorange. Subscript b stands for the wide-lane combination. The time-average value (3) is calculated before and after the cycle slip. Their difference should be close to an integer value:

$$\Delta n \equiv \left(b'_\delta - b_\delta\right) = \Delta n_1 - \Delta n_2 \tag{4}$$

2.3. Calculating the clock's stability

Here we tested the short-term stability of the GPS receiver's clock. We calculated the clock's stability using the Allan variance (ADEV) [1]:

$$\sigma_y^2(\tau) = \frac{1}{2\tau^2}\left\langle\left(\Delta^2 x\right)^2\right\rangle = \frac{1}{2}\left\langle\left(\Delta y\right)^2\right\rangle \tag{5}$$

Modified Allan variance (MDEV) [1],

$$\text{Mod.}\sigma_y^2(\tau) = \frac{1}{2\tau^2}\left\langle\left(\Delta^2 \overline{x}\right)^2\right\rangle \tag{6}$$

Total Allan variance (TDEV) [1] and

$$\sigma_x^2(\tau) = \frac{\tau^2}{3}\text{Mod.}\sigma_y^2(\tau) = \frac{1}{6}\left\langle\left(\Delta^2 \overline{x}\right)^2\right\rangle \tag{7}$$

Overlapping Hadamard variance (HDEV), following the notation given in [6]:.

$$H\sigma_y^2(\tau) = \frac{1}{6(N-3m)\tau^2}\sum_{i=1}^{N-3m}\left[x_{i+3m} - 3x_{i+2m} + 3x_{i+1m} - x_i\right]^2 \tag{8}$$

Overlapping Hadamard variance is used for characterization of rubidium oscillators, because linear frequency does not affect it [6]. Also, power spectral density is calculated, with the population consisted of 86400 samples.

3. RESULTS AND DISCUSSION

3.1. Device under calibration and measurement

We tested a geodetic class, double frequency GPS receiver Trimble NetRS (depicted as DCM in Fig. 1). The receiver collects the code and phase GPS data on 24/7 basis within Serbian Continuously Operating Reference Station (CORS) network. Since a computer running under Linux is incorporated in the NetRS, it is attached directly to Serbian Academic Network and, thus, available throughout the Internet.

We use a high-performance Trimble Zephyr Geodetic GPS antenna, connected to the receiver with a low-noise cable. The antenna is mounted to the highest point of the roof of the building, in order to assure the avoidance of any reflecting surfaces. No radio-sources or voltage cables exist in the vicinity of the antenna.

Everyday use of NetRS belongs to the field of surveying, serving as one of the nodes in the CORS network. However, it is equipped with a 1PPS output, which makes it convenient for time-keeping purposes.

The receivers deliver 8 us wide pulses, with rise and fall times of about 100 ns. Resolution is in the order of 40 ns, with the possibility of accuracy limitation up to +/- 1us, due to position errors, and antenna cable length [17].

3.2 Experiment set-up

A list of instruments involved in our experiment is given in Table 1 and the experiment set-up is depicted in Fig. 1.

No.	**Measuring equipment**				**Remarks**
	Name	Type	Manufacturer	S/N	
1	TIC	CNT-90	Pendulum	914858	
2	NetRS	6609/021	Trimble	914647	Opt 70
3	Digital clock	CADM	Rohde-Schwartz	99.6014.02	
4	Oscillo-scope				

Table 1. Equipment used in the experiment

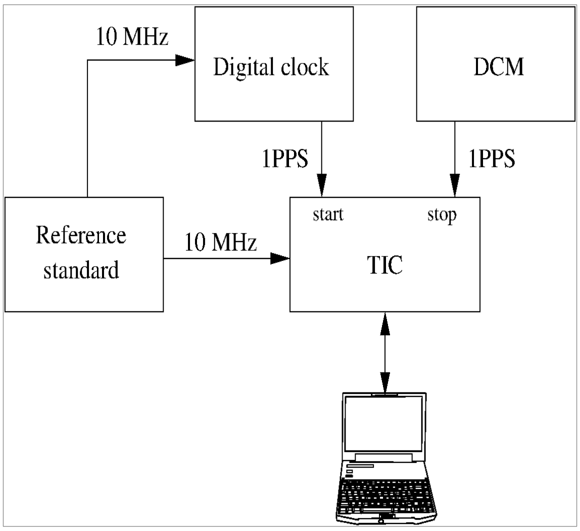

Fig. 1. Experiment set-up

3.3. Time interval measurement

The frequency of the DCM is compared to the reference frequency by means of the measuring phase difference between the two signals and its change in time. The phase difference is estimated by measuring the time interval between the zero crossings of the 1PPS signals using the time interval counter (TIC). Relative frequency offset is calculated by fitting the least-square line to the data and taking the slope of the line. The raw data diagram is given in Fig. 2.

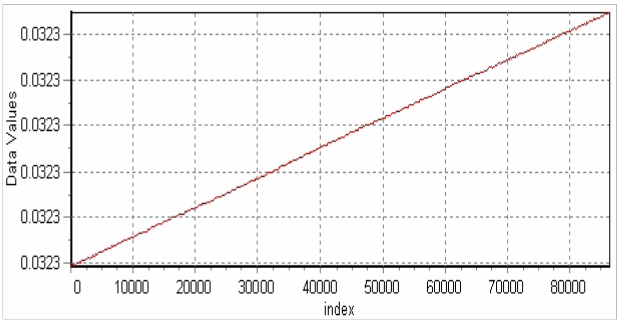

Fig. 2. Raw data

1PPS from the digital clock is applied to the Input A (START), 1PPS from DCM (NetRS GPS receiver) is applied to the Input B (STOP) of the TIC.

Input signal conditioning is as follows:

- DC coupling, 50 Ω, rising edge,
- Setting trigger level: 50% of the signal amplitude (manual triggering), and
- Measurement time: 86400 s.

Data acquisition and processing procedure was performed fully automatic. We used Time View software for data logging and processing. The indoors ambient temperature was constant throughout the experiment, 20°C.

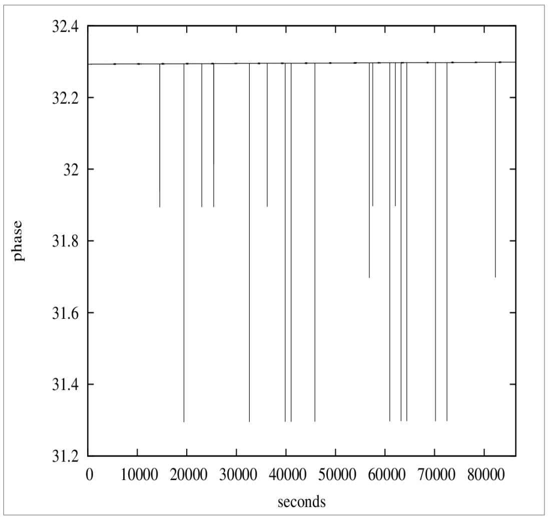

Fig. 3. Phase-time diagram

During the 24 hours session, 16 outliers occurred, depicted as sudden jumps in the phase-time diagram (Fig 3).. After the removal of the outliers, we obtain the final results for the power spectral density (Fig. 4), and Allan variance (ADEV, MDEV, TDEV, and HDEV, Fig. 5).

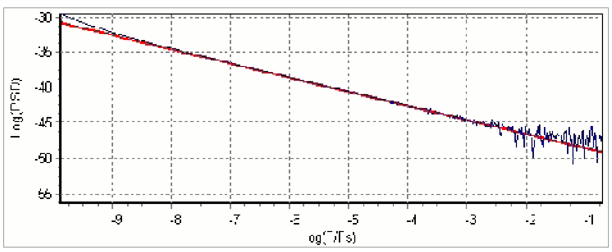

Fig. 4. Power spectral density values

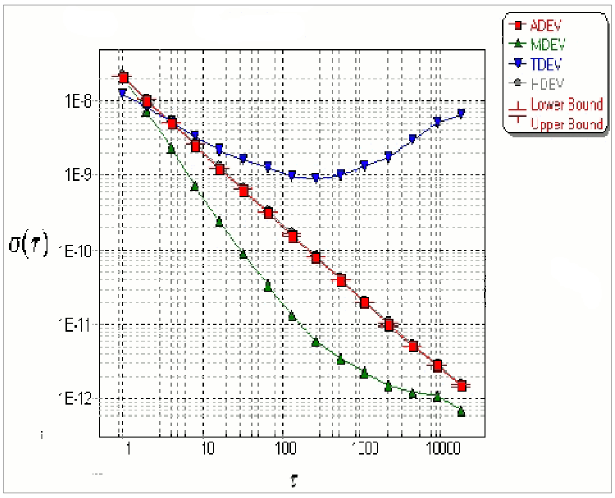

Fig. 5. Allan variance values

However, the amounts of the outliers showed certain regularity in the amount, which was not expected. Their values were grouped around three points: approximately -0.4, -0.6, and -1 ms, compared to the mean value.

If the receiver is moving, the accuracy of its 1PPS is decreasing [12]. Since the receiver used in the experiment is stationary, that source of error is neglected.

After the notification of the outliers, we processed the RINEX file with raw GPS data for cycle slips detection, in order to find the correlation with the outliers in the time-phase diagram. We followed the method described in [3], using the geometry-free and wide-lane linear combinations of raw dual frequency pseudorange and carrier phase data. We used the modules of GPS Toolkit [6], [9].

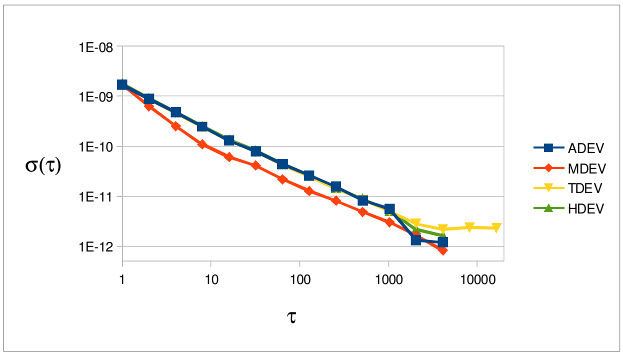

Fig. 6. Allan variances from raw GPS data

There were 56 cycle slips in total, during the 24 hours of data logging. We estimated the clock's stability independently by calculating Allan variances from RINEX data. The results are given in Fig. 6.

No correlation between the epochs of the cycle slips and outliers in 1PPS were found, which means that the satellite constelation did not effect the 1PPS performance.

Considering the experiment set-up, ambient conditions (indoors and outdoors), examining the change of the satellite constellation, we did not find what caused the outliers in 1PPS coming from the NetRS. They do not affect the everyday use of NetRS (surveying, positioning, and time-keeping in LAN), but could seriously degrade the accuracy of certain time-critical applications. Therefore, we are preparing the extension of the experiment, in order to investigate the problem.

4. CONCLUSION AND REMARKS

According to overall results of our 24 hours measuring session, it can be concluded that a geodetic class GPS receiver is capable of permanent delivering time marks within the ms accuracy. Examples of such application are permanent monitoring of an industrial process, or time synchronization between distant computer nods in a wide-area network.

Still, when higher accuracy is needed, in the order of microseconds or better, a special attention should be paid to the set-up of the equipment, keeping in mind what disturbances of the GPS signal could occur during the exploitation.

The outliers that occurred in our experiment could seriously degrade the accuracy of real-time applications. We did not find any relation between the obtained results and the experiment (set-up, ambient conditions, or satellite constellation). The grouping of the outliers in the mean of values and their irregularity considering the time epochs when they occurred, should be investigated further. We suggest another, longer experiment, which would last for seven days, in order to find the factor that causes outliers.

The mentioned outliers could degrade also the positional accuracy. The solution for high-precision surveying purposes is to discipline the GPS clock with an external reference, such is a rubidium standard.

5. ACKNOWLEDGEMENTS

The authors of the paper express their gratitude to the Ministry of Education and Science of the Republic of Serbia, who supported the work on this paper by participating in the project of technological development TR-36048.

6. REFERENCES

[1] Allan, D. W. , Ashby, N., Hodge, C. C.: "The Science of Timekeeping", Hewlett Packard Application Note 1289; 1997.

[2] Behrendt K, Fodero, K., "The Perfect Time: An Examination of Time Synchronization Techniques", In Transmission and Distribution Conference and Exposition, 2010 IEEE PES", April, 19-22, 2010., New Orleans LA, pp. 1-8, 2010.

[3] Blewitt, G., "Carrier Phase Ambiguity Resolution for the Global Positioning System Applied to Geodetic Baselines up to 2000 km", Journal of Geophysical Research, vol. 94, No. 88, pp. 10,.187-10,203, 1989.

[4] Blewitt, G. et al., "An Automated Editing Algorithm for GPS Data", Geophysical Research Letters, vol. 17, no. 3, pp. 199-202, 1990.

[5] Carta, A. et al., "GPS and IEEE 1588 Synchronization for the Measurement of Synchrophasors in Electric Power

Systems", Computer Standards & Interfaces no 33, pp. 176-181., 2011.

[6] Craddock, T. et al, "The GPS Toolkit: Open Source Clock Tools", In Proceedings of the 40th Annual Precise Timing and Time Interval (PTTI) Meeting, December 01-04, 2008., Reston, VA, pp 275-274., 2008.

[7] Dickerson, B., "Time in the Power Industry: How and Why We Use It", White paper, Arbiter Systems, available at http://www.arbiter.com/files/product-attachments/TimeInThePowerIndustry.pdf

[8] Elson, J., Estrin, D., "Time Synchronization for Wireless Sensor Networks", In Proceedings of the 2001 International Parallel and Distributed Processing Symposium (IPDPS), San Francisco, CA, USA, pp. 1965--1970, 2001.

[9] Gaussiran, T. et al., "An Open Source Toolkit for GPS Processing, Total Electron Content Effects, Measurements and Modelling", In Proceedings of the International Beacon Symposium 2004. October 18-22. 2004., Trieste, Italy. 2004.

[10] Hämälainen, P. et al., "Design and Implementation of Real-time Betting System with Offline Terminals", Electronic Commerce Research and Applications no 5, pp. 170-188., 2006.

[11] Heursch, A., "Using Standard Operating Systems for Time Critical Applications with Special Emphasis on LINUX", PhD Dissertation, Universität der Bundeswehr München, Fakultät für Informatik, 2006.

[12] Hightower, P., "Motion Effects on GPS Receiver Time Accuracy", Instrumentation Technology Systems, Northridge, CA, 2008.

[13] Lombardi, M., "NIST Time and Frequency Services", NIST Special Publication 432, NIST, 2002..

[14] McCarthy, D., "Using UTC to Determine the Earth's Rotation Angle", in Decoupling Civil Timekeeping from Earth Rotation, Science and Technology Series, vol. 113, pp. 105-117, 2011.

[15] Ogrizović, V, "A Cconstruction of an Advanced Measuring System for Astro-Geodetic Determinations", Publ. Astron. Obs. Belgrade, no 86, pp. 145-150., 2009.

[16] Schildknecht, T., Dudle, G., "Time and Frequency Transfer: High Precision Using GPS Phase Measurements", GPS World, Feb. 2000, pp. 48-52, 2000

[17] Trimble: NetRS "GPS Receiver - User Guide", Trimble Navigation Limited, 2004.