SAUCIS
Sakarya University Journal of Computer and Information Sciences
http://saucis.sakarya.edu.tr/
SAKARYA UNIVERSITY
DOI: 10.35377/saucis...1215689
RESEARCH ARTICLE

Conjoint Analysis of GPS-Based Orbit Determination among Traditional Methods

İbrahim Öz [1], Cevat Özarpa [2]

[1] Ankara Yıldırım Beyazit University, Technology Transfer Office; Ankara, Türkiye
[2] University of Karabük, Mechanical Engineering Department; Karabük, Türkiye

Corresponding author:
İbrahim Öz, Ankara Yıldırım Beyazit University, Technology Transfer Office; Ankara, Türkiye
E-mail address:
ibrahimoz@gazi.edu.tr

Submitted: 9 December 2022
Revision Requested: 1 September 2023
Last Revision Received: 13 September 2023
Accepted: 30 September 2023
Published Online: 30 September 2023

Citation: Öz İ. Özarpa C. (2023). Conjoint Analysis of GPS-Based Orbit Determination among Traditional Methods. *Sakarya University Journal of Computer and Information Sciences*. 6 (3)
https://doi.org/10.35377/saucis...1215689

ABSTRACT

This Satellite operators rely on accurate satellite orbit estimation to ensure safe orbital operations, considering the influence of external forces. Traditional methods, such as single station angles and range (AZEL), along with range-to-range (RNG) techniques, have been widely employed by operators. However, the use of GPS signals for determining the orbits of geostationary communication satellites (GEO) has gained popularity due to its effectiveness. Extensive research has validated the reliability and efficiency of GPS-based GEO orbit determination. In this study, the performance of the GPS-based method is evaluated by comparing it with flight-proven techniques. Three GEO communication satellites located at different longitudes were analyzed using GPS-based, RNG-based, and AZEL-based methods. The results indicated that the GPS-based determined orbit had a root mean square error (RMSE) of 75.887 m, 372.420 m, and 768,223 m for Satellites A, B, and C, respectively, when compared with the RNG-based determined orbit. Similarly, the RMSE between the GPS-based and AZEL-based determined orbits was 133.287 m, 242.076 m, and 764.866 m for Satellites A, B, and C, respectively. These findings strongly support using GPS-based orbit determination, as it aligns with the results obtained from flight-proven RNG and AZEL methods. The study demonstrates the reliability and accuracy of the GPS-based orbit estimation method. Consequently, it encourages satellite operators to adopt GPS-based navigation for precise determination of communication satellite orbits. The comparison between AZEL vs. GPS and RNG vs. GPS methods reinforces the advantages of utilizing GPS-based navigation.

Keywords: Orbit determination, GPS based orbit, navigation, GEO orbit

1. Introduction

This Geostationary (GEO) satellites seem fixed from the Earth; however, satellite orbit motion deviates from theoretical orbital motion due to perturbing forces. Those are the gravitational forces of the sun and the moon, the earth's non-uniform mass distribution, solar pressure, and other small forces. Maneuvers balance perturbing forces act on a GEO satellite [1]– [3]. It is mandatory to determine the orbit of a satellite for operators. There are various types of data collection, observation, and orbit determination methods for orbit estimation; subsequently, the orbit has always been subject to change due to external forces. The two most common ways of orbit determination are range measurement, bi-static range measurement from two ground stations, and single station tracking based on azimuth elevation [4], [5]. Global Positioning System (GPS) is becoming a gorgeous method for the orbit determination of GEO satellites. However, GEO satellite operators mainly use traditional ground-based measurement systems for orbit determination [6]. In GPS-based orbit estimation, the data acquisition system is inside the GPS in low earth orbit (LEO) and ground receiver cases. Nevertheless, in the GEO satellite case, the orbit is beyond the GPS constellation. GPS satellites' altitudes (~22000km) are lower than GEO satellite's altitude (~35786 km), and the earth shadows the GPS signals most of the time. However, utilizing GPS signals for accurate orbit estimation of GEO satellites is still promising.

GPS is a satellite navigation system that can provide highly accurate position and timing information in all weather conditions worldwide. The onboard satellite GPS receiver calculates the pseudo-range distance between the GEO satellite (user) and the recognized GPS satellite. The GPS signal is subject to factors that degrade signal quality and cause GEO satellite position inaccuracies, such as clock errors, multipath propagation, ephemeris uncertainty, and ionosphere and troposphere delay. The number of visible GPS satellites and satellite geometry from the user's point of view also affect the accuracy [7].

There are many studies on GPS-based orbit determination in different aspects. According to some researchers, real-time onboard GPS orbit determination was developed to provide a very accurate orbit. The reliability of uncertainty was one of the essential parameters in orbit determination (OD). The characterization of GPS uncertainty was analyzed in different aspects. The uncertainties were analyzed, and the effect of factors was estimated for the GEO orbit [8, 9].

GPS-based orbit determination of GEO satellites is becoming an attractive approach. The accuracy of GNSS systems was studied, such as the GEO satellite called JS-2 equipped with high gain GNSS antenna, amplifiers, and high sensitivity receivers. Weak GPS signals and the onboard orbit determination filters were investigated to improve OD performance. The analysis of carrier-to-noise ratio density (C/N0), position dilution of precision (PDOP), availability of signal, and characteristics result in excellent OD performance [10, 11].

There are various articles about GEO satellite orbit determination using GPS receivers. GEO orbit determination accuracy is about 20 m, according to the GPS receiver and orbital filter performance assessment study. The precision requirements of GEO satellites were identified with a simulator of GPS signals and a single-frequency receiver.

A European project demonstrated an on-board receiver that acquire weak signal to increase the number of visible GPS satellites. Flight performance was demonstrated by signal processing and onboard orbit determination.

GPS-based navigation for lunar missions is an emerging field with several publications. GNSS flight experiments show beneficial results for lunar navigation applications [11].

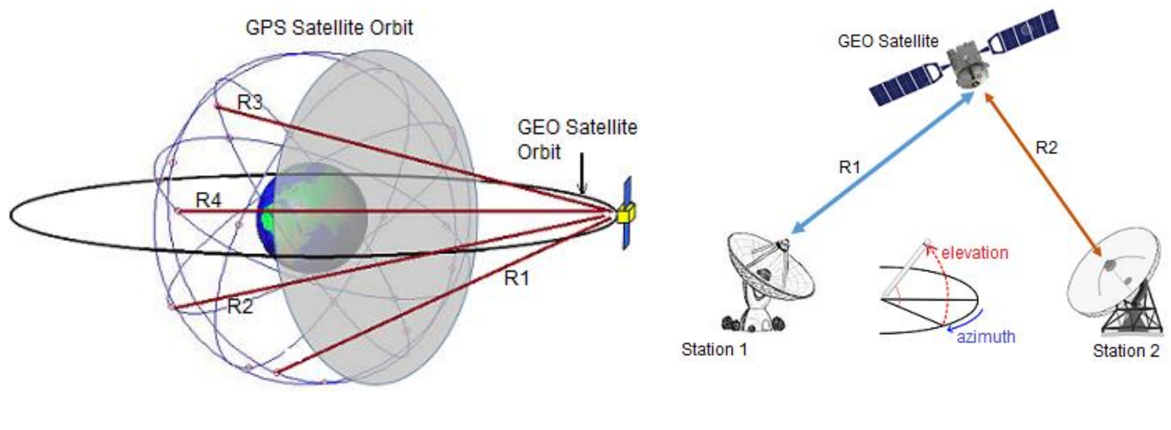
The GEO orbit is used mainly for telecommunication purposes and is unique. GPS-based navigation methods offer some advantages over ground-based methods. Capuano Vincenzo et al. studied the best GNSS signal for GEO navigation and achieved reliable performances [12].

Jun Zhu et al. investigated GPS-based navigation performance for GEO satellite telecommunication to determine the signal quality effect on OD. The results provide sub-meter-level precision [13].

The Extended Kalman Filter (EKF) method was developed for real-time and onboard OD by Chiaradia Ana et al. They analyzed the model's accuracy and performed simple and relatively accurate orbit determination. The obtained velocity and position errors vary in a reasonable range along a day [14, 15].

Researchers established and analyzed GPS and GEO-based integrated networks to find a GPS receiver's user position or position coordinates in another work. They developed a new approach for determining the minimum dilution of precision with an integrated network. [7]

There are various studies on GEO satellite orbit determination based on GPS navigation. In particular, no study, to our knowledge, has validated GPS-based OD by comparing traditional flight-proven, frequently used RNG and AZEL methods. The GEO satellite operators and manufacturers need encouragement to use GPS-based orbit determination. Providing evidence about the performance of GPS-based OD by showing consistent results with flight-proven and frequently used methods would be very appreciated. Our research aims to assess the GPS-based OD with flight-proven methods. This study investigates a GPS-based orbit determination performance for GEO communication satellites by comparing the GPS with the classical angle and range measurement.



(a) (b)

Figure 1 (a) GPS-based orbit determination for GEO orbit (b) AZEL and RNG-based orbit determination methods.

2. Observation and Orbit Determination Methods

There are many observation methods to gather orbital data for orbit estimation. In this work, two commonly utilized methods among satellite operators, single station tracking and measurement of azimuth, elevation, and range (AZEL) and the distance measurement from the ground station to satellite called ranging (RNG) methods were utilized to collect data for orbit estimation. Since those are flight-proven and frequently utilized methods, comparing GPS-based OD with these two methods would be more meaningful for the satellite operators.

Figure 1 (a) shows pseudo-range measurements between GEO and GPS satellites. The GEO satellite cannot receive the signals of GPS satellites in gray shaded [5]. Figure 1(b) shows range and angle measurements [6]. In the range-to-range (RNG) method, the distance between ground Station 1, the GEO satellite and ground Station 2, and the GEO satellites are measured simultaneously. The antenna azimuth, elevation angle to the GEO satellite and the range are measured simultaneously in azimuth elevation (AZEL) type observation.

2.1 Azimuth Elevation and Range Method (AZEL)

The single-station tracking method is the most traditional way to gather orbital data for orbit determination. In this method, a ground station antenna follows a GEO satellite, and azimuth-elevation angle and range data were gathered to estimate the orbit. This method is mainly utilized and flight-proven methods among satellite operators.

In this method, a single station position vector of is defined as an R_{GS} in earth-centered earth fixed (ECEF) coordinate. The satellite position vector, R_{sat}, can also be expressed in the ECEF coordinate system. The range vector of the distance between the ground station and the satellite is shown in Equations 1.

$$\rho = \|R_{Sat} - R_{GS}\| + \Delta_{\rho}\Delta\rho + v_{\rho} \quad (1)$$

Here, Δρ is the range offset, and vρ show the range noise. We represent the station to satellite vector of the topocentric frame using a transformation of coordinate; Topo-centric ECEF can be defined in Equation 2 as,

$$\rho_{Topocentric} = C_{ECEF}^{Topocentric}(R_{Sat} - R_{GS}) \quad (2)$$

The angles-tracking data, azimuth, and elevation are obtained from the combination of each range, as shown in Equations 3 and 4 [6].

$$Az = atan2(\rho_y/\rho_x) \quad (3)$$

$$El = acos(\rho_z/\rho) \quad (4)$$

The Keplerian orbital parameters in Table 1 were calculated using range-range observation data for three satellites, Sat A, Sat B, and Sat C.

Table 1 Table Classical (Keplerian) orbital parameters of the considered satellite orbits obtained using the AZEL method.

Satellite/ Method	**SMA (km)**	**Ecc**	**Incl (deg)**	**RAAN (deg)**	**ArgPer (deg)**	**TrueAn (deg)**
Sat A / AZEL	42165.049	9.12E-05	0.048062	282.527	342.499	353.358
Sat B / AZEL	42165.056	9.35E-05	0.048915	302.152	331.043	4.181
Sat C / AZEL	42164.533	7.32E-05	0.047396	258.838	355.294	341.764

Those data were collected using the AZEL observation method. The sequential processing technique was utilized to obtain the classical orbital parameters.

2.2 Ranging Method (RNG)

The RF signal emitted from the ground station is received and re-transmitted from the satellite. The re-transmitted signal is received via the ground station. After performing the necessary process, the range between the ground station and the satellite is obtained as range data [16].

The range from a ground station to a satellite can be defined in the following Equation 1.

$$\rho_{i1} = |R_{sat} - R_{GSi}| + c\tau_{delay} + \Delta d_{trop} + \Delta d_{ion} + \varepsilon \quad (5)$$

Where; ρ: station to satellite distance, R_{SAT}: satellite position vector, R_{GS}: ground station position vector, c: speed of the light, τ: ground station and transponder time delay, Δd_{trop}: tropospheric delay, Δd_{ion}: ionospheric delay, ε: other errors

Table 2 Table Classical (Keplerian) orbital parameters of the considered satellite orbits obtained using the RNG method.

Satellite/ Method	SMA (km)	Ecc	Incl (deg)	RAAN (deg)	ArgPer (deg)	TrueAn (deg)
Sat A / RNG	42165.055	9.12E-05	0.048068	282.529	342.392	353.463
Sat B / RNG	42165.056	9.35E-05	0.048915	302.152	331.043	4.181
Sat C / RNG	42164.558	7.33E-05	0.047476	258.815	354.894	342.186

The range observation data was utilized to estimate Keplerian orbital parameters. The calculated classical parameters are shown in Table 2, and those values will be a reference to assess GPS-based measurement results.

2.3 GPS-based method

GEO satellites can receive GPS signals from the main or side lobe, although geo orbit is higher than GPS orbit. In this method, onboard GPS receivers acquire the signal from known GPS satellites and process raw data. This work uses C/A (clear/ acquisition) code pseudo-range measurement to calculate the range between GEO satellites and GPS satellites.

GPS satellite's C/A signal code pseudo-range in L1 frequency can be expressed in Equation 6,

$$\rho_c = \rho + c[\Delta t_{GPS}(t) - \Delta t_U(t)] \quad (6)$$

where ρ_c: CA code pseudo-range in L1, c: speed of light, Δt_{GPS}: clock offset of GPS satellite, Δt_U: clock offset of a receiver, t: instant observation time, ρ: 3D distance between onboard GEO satellite receiver and GPS satellite.

$$\rho = \sqrt{(x_{GPS} - x)^2 + (y_{GPS} - y)^2 + (z_{GPS} - z)^2} \quad (7)$$

Where x, y, z: position of the GEO satellites, X_{GPS}, Y_{GPS}, and Z_{GPS}: position of the GPS satellite.

Table 3 provides calculated Keplerian parameters of three GEO satellites using GPS pseudo-range data. This method is called GPS-based navigation.

Table 3 Classical (Keplerian) orbital parameters of the considered satellite orbits.

Satellite/ Method	SMA (km)	Ecc	Incl (deg)	RAAN (deg)	ArgPer (deg)	TrueAn (deg)
Sat A / GPS	42165.055	9.12E-05	0.048068	282.529	342.392	353.463
Sat B / GPS	42165.059	9.40E-05	0.048825	302.187	331.137	4.052
Sat C / GPS	42164.537	7.32E-05	0.047394	258.832	355.206	341.858

The orbital parameters in Table 1 and Table 2 were used to assess GPS-based navigation method performance. It is expected to have quite identical orbits with orbits obtained using other AZEL and RNG methods [17, 18].

In this work, considering communication satellites' Keplerian parameters are expressed in J2000, the earth-centered inertial (ECI) coordinate system. The X points toward the mean vernal equinox of the Earth on 1 January 2000, at 12:00:00:00 UTC, in the J2000 system. The satellites are assumed to have 2500 kg mass, c_d=0.2 c_r=1.3, and a solar pressure area of 60 m^2. The collected data for one satellite is 144 samples for each method. The total collected data is 1296 samples.

2.4 Orbit Determination and Analysis Method

GPS, AZEL, and RNG observation data were used to calculate the Keplerian orbit parameters, also known as classical orbital parameters. The same orbit determination method, namely the Sequential Process Method, was applied to calculate the satellite orbits for all three types of observation data. A Sequential Process (SP) Kalman filter was employed consistently across the three methods to analyze the impact of the observation data on orbit determination. The resulting orbital parameters are presented in Table 1, Table 2, and Table 3.

To evaluate the differences in the obtained orbits, the orbits were propagated for 48 hours with a time interval of 20 minutes. Statistical analyses were conducted to assess the root mean square error (RMSE) and standard deviation (Std Dev) of the orbit differences. These analyses were performed using the propagated orbital data from each method, with a high significance level. Additionally, data analysis studies involving RMSE and Std Dev were carried out, and graphical representations were created for all three methods, considering three satellites located at different orbital positions.

3. Results and Discussion

This paper compares using a GPS receiver in communication satellite orbit determination with operators' widely used methods. We evaluated classical (Keplerian) orbital elements of three observation data sets for three satellites using the GPS, RNG, and AZEL methods. Those parameters were propagated for 48 hours with a 20-minute interval for each method starting from an epoch. All methods produced their results, and there are some differences between them. The principal focus of this work was to calculate the similarity of orbits obtained using each method. The GPS-based navigation method results are compared with traditional orbit determination methods RNG and AZEL.

This work outlines the performance of a GPS receiver usage for orbit determination of communication satellites by comparing it with traditional single-station tracking (AZEL azimuth, elevation range measurement) and two-station range-to-range (RNG) measurement. Three GEO satellites at different orbital locations were utilized in this work, and classical orbital element are given in Table 1, Table 2, and Table 3.

The performance of the GPS method can be evaluated by analyzing the differences between the RNG and AZEL methods. The results obtained using each data set have been compared in terms of radial, along-track, cross-track, and range (3D distance).

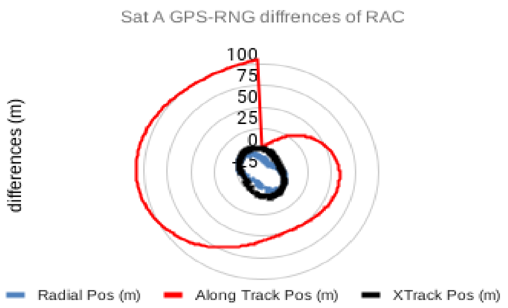
The orbits are compared, and the differences have been calculated in all spatial directions to analyze the obtained orbital parameters in three data collection methods. Table 4 provides differences between the GPS versus the RNG method and the GPS versus the AZEL method in the radial, along-track, and cross-track direction for three satellites. The maximum value of RMSE is 768.173 m in Sat C along-track direction. Similarly, the worst standard deviation is 49.159 m in the Sat B cross-track direction.

The results below represent that using GPS receivers proposes good enough performance for orbit determination.

Table 4 Sat A, Sat B and Sat C spatial (RAC) position differences between GPS and RNG and GPS and AzEl.

Satellite Name	Statistics	RNG - GPS			AZEL - GPS		
		Radial	Along Track	X Track	Radial	Along Track	X Track
Sat A	StDev	5.419	30.843	3.596	12.420	47.855	37.437
	RMSE	7.702	75.410	3.583	13.659	127.228	37.308
Sat B	StDev	9.246	18.943	43.724	15.089	41.658	49.159
	RMSE	9.238	369.747	43.573	15.429	236.564	48.989
Sat C	StDev	2.183	10.974	9.129	12.593	38.552	2.746
	RMSE	3.052	768.173	9.098	13.085	764.749	2.737

Figure 2 a. and b. show detailed radar views of GPS vs. RNG and GPS vs. AZEL method in radial, along-track, and cross-track directions differences for 48 hours and Sat A. The prediction difference in RMSE in the radial, along-track, and cross-track directions are 7.702 m, 75.410 m, and 3.583 m, respectively, for the Sat A GPS-RNG method. GPS-AZEL method position differences for Sat A are similar to GPS-RNG method position differences. The graph has shown promising results in all spatial directions.



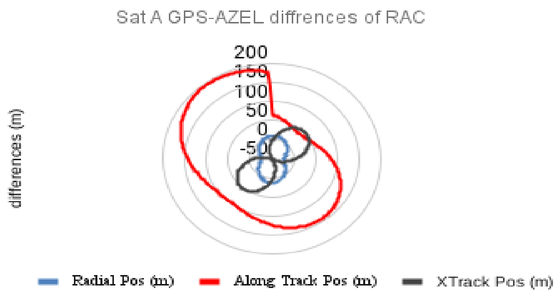


Figure 2 (a) The details of differences of orbits in RAC directions, obtained from GPS-based and RNG based method for Sat A (b) The details of differences of orbits in RAC directions, obtained from GPS-based and AZEL-based method for Sat A, in radar view.

Figure 3 a) and Table 4 present the differences between the GPS-based obtained orbit and RNG-based obtained orbit for Sat B. The left vertical axis in red color shows details of along-track position differences. The right vertical axis in blue and black shows radial and cross-track differences, and the horizontal axis shows time in an hour for both Figures 3a) and 3 b). The RMSE errors are 9.238 m, 369.747 m, and 43.724 m. simultaneously, standard deviation values are 9.246, 18.943, and 43.724 in radial, along-track, and cross-track directions, respectively. The maximum difference between GPS-based and AZEL-based calculated orbit is 236.564 m in the along-track direction. The differences between models are due to measurement errors and the accuracy of the dynamic satellite model.

These results are in line with expectations and less than the maximum allowed error of 1582 m value.

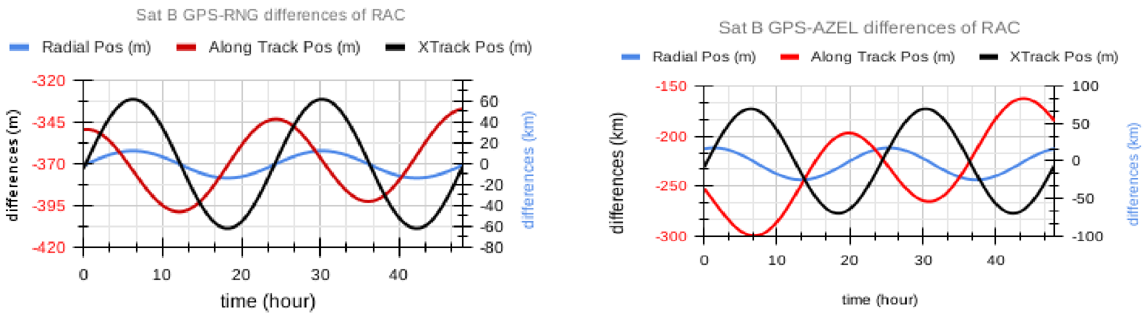


Figure 3 (a) The details of differences of orbits in RAC directions, obtained from GPS-based and RNG based method for Sat B (b) The details of differences of orbits in RAC-directions, obtained from GPS-based and AZEL-based method for Sat B, in the time axis.

Table 4 and Figure 4 a) compare calculated orbits using GPS-based and RNG-based measurements for Sat C. The left vertical axis in red color shows details of along-track position differences. The right vertical axis in red shows cross-track differences, the left vertical axis in blue color shows radial position, and the horizontal axis shows along-track position differences for both Figure 4 (a) and Figure 4 8b). Figure 4 (a) shows position differences in radial and cross-track directions between GPS-based and RNG-based orbits. Similarly, Figure 4 (b) shows position differences in radial and cross-track directions for Sat C between GPS-based and RNG-based orbits. The differences in all directions for the two methods are less than 1582 m success criteria and about 780 m. Standard deviations are slight, and the distribution of data is at an acceptable level. Consequently, evaluating GPS-based determination using Sat C orbits as a sample shows a perfect correlation between flight-proven and GPS-based orbits.

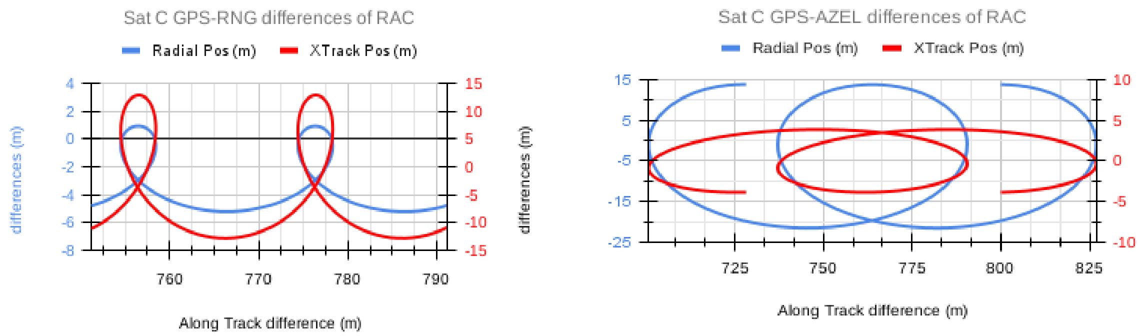


Figure 4 (a) The details of differences of orbits in radial and cross-track directions, obtained from GPS-based and RNG based method for Sat B (b) The details differences of orbits in radial and cross-track directions, obtained from GPS-based and AZEL based method for Sat B, in distributed view and x-axis shows along-track differences

As seen from Figures 4 a and b, the variations in RAC directions have a low level of fluctuation. Still, the fluctuation in the along-track direction is relatively higher. The fluctuation is primarily due to solar pressure and the accuracy of dynamic satellite models of Sat A.

The differences in Figures 2, 3, and 4 are less than 1 km. The results are auspicious and validate GPS-based navigation with flight-proven and widely used methods among satellite operators.

Table 5. Statistical summary of 3D position differences of the argued methods for all three satellites

Sat Name	RMSE (RNG- GPS)	RMSE (AZEL-GPS)	Stdev (RNG- GPS)	Stdev (AZEL- GPS)
Sat A	75.887	133.287	29.873	44.467
Sat B	372.420	242.076	18.996	40.481
Sat C	768.233	764.866	10.981	38.548

The actual physical distance (3D) between the based method and the other two methods was investigated for three satellites. 3D differences in RMSE and standard deviation values are calculated and tabulated in Table 5.

GPS-based and RNG-based determined orbit RMSE of 3D differences are 75.887 m, 372.420m, and 768.223 m for Sat A, Sat B, and Sat C, respectively. GPS versus AZEL orbit 3D differences are small and similar to GPS vs RNG-based 3D orbit differences. Similarly, AZEL-based and GPS-based determined orbit RMSE of 3D position differences are 133.287 m, 242.076 m, and 764.866 m for Sat A, Sat B, and Sat C, respectively. Small standard deviation values imply that the orbits are identical to each other.

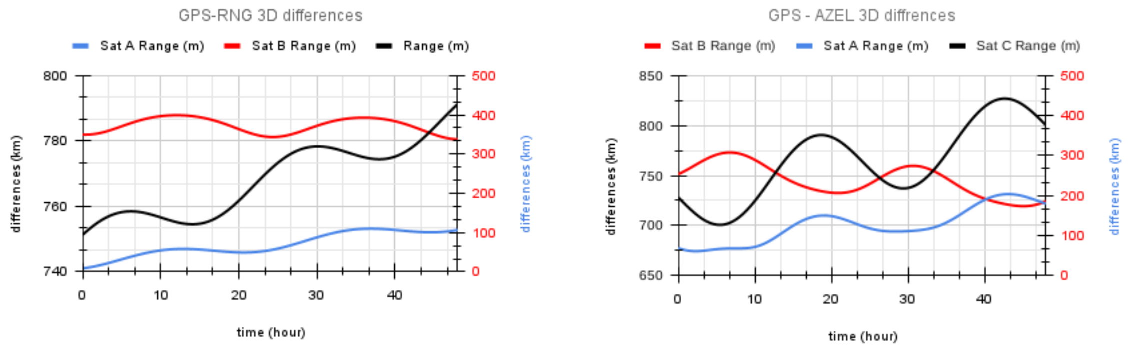


Figure 5 (a) The details of differences of orbits in 3D, obtained from GPS-based and RNG-based method for Sat C (b) The details of differences of orbits in 3D, obtained from GPS-based and AZEL-based method for Sat C, in the time axis.

Figure 5 (a) compares the orbits of three GEO satellites at different longitudes. The left vertical axis in black color shows details of 3D position differences of Sat C—the right vertical axis in red and blue shows 3D differences between Sat A and Sat B.

Table 5 values and Figure 5 graphics are in line with expectations, and errors are less than the success criteria [19, 20].

The literature contains several studies resembling GPS-based orbit determination from various perspectives. One such study is "Real-Time Multi-GNSS Precise Orbit Determination Based on the Hourly Updated Ultra-Rapid Orbit Prediction Method" [21]. This research focuses on evaluating accuracy through a frequent data-receiving approach. It delves into the analysis of both BDS (BeiDou Satellite System) and GPS side-lobe observation quality, providing insights into the impact of side-lobe effects on-orbit accuracy.

Another relevant work is "Orbit Determination with a GEO Satellite Onboard Receiver" [22]. This study evaluates orbit determination by employing a GEO satellite onboard receiver. It particularly investigates how the presence of such a receiver influences orbit accuracy, shedding light on the intricacies of using GPS in this context.

Furthermore, the research titled "Orbit Determination for All-Electric GEO Satellites Based on Space-Borne GNSS Measurements" [23] is another noteworthy contribution. This study explores the utilization of space-borne GNSS (Global Navigation Satellite System) measurements for orbit determination, emphasizing its relevance for all-electric GEO (Geostationary Earth Orbit) satellites.

These studies collectively demonstrate the diverse applications of GPS in satellite orbit determination, each offering unique insights into its use from different angles and contexts. This body of research highlights the versatility and efficacy of GPS-based methods in advancing our understanding of satellite orbits and enhancing their precision.

The present research validates and reinforces strong support for GPS-based orbit determination. The well-established flight-proven RNG and AZEL methods, known and trusted by satellite operators, provided compelling evidence in favor of the GPS-based orbit determination method.

4. Conclusion

The evolution in data collecting and processing methods in OD has enforced the satellite operators to look for unconventional OD methods. OD methods should provide satellite operators with precise orbit parameters and cost-effective, reliable, and sustainable solutions.

The accuracy of GPS-based range measurement via onboard GEO satellites was investigated. Related estimated orbit accuracy is discussed by comparing traditional frequently utilized flight-proven single station tracking and range-range methods in this work. This research suggests that GPS-based OD provides a reliable solution compared to single-station tracking and range-range methods. The results from three satellite longitudes indicate that satellite operators can utilize GPS-based navigation for orbit determination. The results agree with flight-proven AZEL and RNG method's orbit parameters.

Finally, our comparison between the AZEL vs. GPS and RNG vs. GPS methods has confirmed the viability of GPS-based navigation for accurately estimating the orbit of communication satellites.

References

[1] H. Li, "Geostationary satellites collocation," Springer, pp. 10-98, 2014.

[2] I. Oz, and U. C. Yılmaz, "Determination of Coverage Oscillation for Inclined Communication Satellite," *Sakarya University Journal of Science*, 24.5: 973-983, 2020.

[3] I. Oz, "Coverages stabilization of an inclined orbit communication satellite with two axis biases," *Journal of The Faculty of Engineering and Architecture of Gazi University*, 38.1: 219-229, 2022.

[4] B. Schutz, T. Byron, and H. B. George, "Statistical orbit determination," Elsevier, pp. 1-210, 2004.

[5] I., Oz, U. C. Yilmaz, and U. Guler, "Performance Assessment of a Turn Around Ranging in Communication Satellite Orbit Determination," *Sakarya University Journal of Computer and Information Sciences* 4.1, 73-83., 2021.

[6] M. Wang, et al. "GNSS-based orbit determination method and flight performance for geostationary satellites," *Journal of Geodesy* 95.8: 1-15., 2021.

[7] U. K. Acharjee, A. Anis, and R. Shahida, "Performance analysis of navigation by the integration of GPS-24 with LEO & GEO," *2007 10th international conference on computer and information technology*. IEEE, 2007.

[8] A. Cano, et al. "Covariance Determination for Improving Uncertainty Realism in Orbit Determination and Propagation," *Advances in Space Research*, 2022.

[9] A. Cano, et al., "Improving Orbital Uncertainty Realism Through Covariance Determination in GEO," T*he Journal of the Astronautical Sciences*, 69.5: 1394-1420., 2022.

[10] A. Chiaradia, P. M. Ana, K. K. Hélio, and F. Antonio, "Onboard and real-time artificial satellite orbit determination using GPS," *Mathematical Problems in Engineering*, 2013.

[11] M. Guan, T. Xu, M. Li, F. Gao, D. Mu, "Navigation in GEO, HEO, and Lunar Trajectory Using Multi-GNSS Sidelobe Signals," *Remote Sensing*, 14(2), 318., 2022.

[12] V. Capuano, et al. "High accuracy GNSS based navigation in GEO." *Acta Astronautica* 136: 332-341., 2017.

[13] Z. Jun, et al. "High Accuracy Navigation for Geostationary Satellite TTS-II via Space-borne GPS." *2020 39th Chinese Control Conference (CCC)*. IEEE, 2020.

[14] Y. Hwang, et al., "Orbit determination accuracy improvement for geostationary satellite with single station antenna tracking data," *ETRI journal*, 30.6: 774-782., 2008.

[15] D. Fasbender, et al. "A Simple Similarity Index for the Comparison of Remotely Sensed Time Series with Scarce Simultaneous Acquisitions," *Remote Sensing* 11.13: 1527, 2019.

[16] M. Wang, et al., "GNSS-based orbit determination method and flight performance for geostationary satellites," *Journal of Geodesy*, 95.8: 1-15., 2021.

[17] U. K. Acharjee, A. Anis; R. Shahida, "Performance analysis of navigation by the integration of GPS-24 with LEO & GEO," *2007 10th international conference on computer and information technology. IEEE*, p. 1-6., 2007.

[18] I. Oz, "GEO satellite orbit determination using spaceborn onboard receiver," Politeknik *Dergisi*, 1-1., 2022.

[19] I. Oz, U.C. YILMAZ, U. Guler, "Tdoa Based Tracking Measurement for Geo Satellites Orbit Determination: Evaluation for The Satellite Operators," *Eskişehir Technical University Journal of Science and Technology A-Applied*

Sciences and Engineering, 23.1: 137-148., 2022.

[20] S. Pessina, et al. "Operational Concepts Refinement for The Orbit Determination of Meteosat Third Generation," I*nternational Symposium on Space Flight Dynamics (ISSFD).* 2017.

[21] B. Tan, et al. "Real-Time Multi-GNSS Precise Orbit Determination Based on the Hourly Updated Ultra-Rapid Orbit Prediction Method.", Remote Sensing, 14(17), 4412, 2022.

[22] W. Li, K., et al." BDS and GPS side-lobe observation quality analysis and orbit determination with a GEO satellite onboard receiver.", *GPS Solutions*, 27(1), 18, 2023.

[23] W. Lu, H. Wang, G. Wu, Y. Huang, Y. "Orbit determination for all-electric geo satellites based on space-borne GNSS measurements.", *Remote Sensing*, 14(11), 2627, 2022.

Conflict of Interest Notice

The authors declare that there is no conflict of interest regarding the publication of this paper.

Ethical Approval and Informed Consent

It is declared that during the preparation process of this study, scientific and ethical principles were followed, and all the studies benefited from are stated in the bibliography.

Availability of data and material

Not applicable

Plagiarism Statement

This article has been scanned by iThenticate ™.