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GEO satellite orbit determination using spaceborn onboard receiver

Yere eşlenik uydularda tümleşik uzay tabanlı alıcılar kullanarak yörünge belirleme

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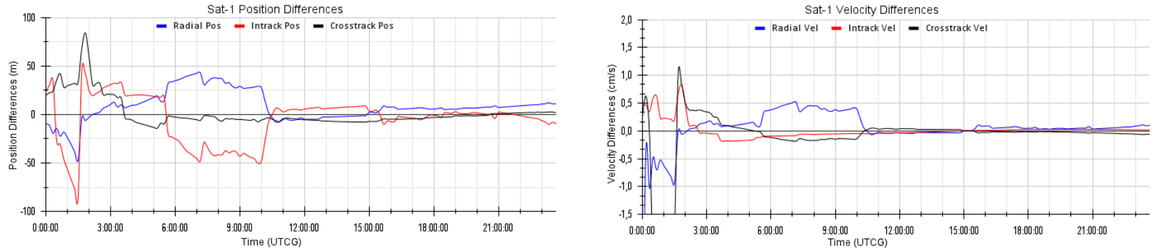
GEO Satellite Orbit Determination Using Spaceborn Onboard Receiver

Highlights

- *Onboard space-born GPS receiver pseudo-range data was proposed for precise orbit determination of communication satellites.*
- *The observation (measurement) pseudo-range data was investigated for reliable and sustainable orbit determination operation of the satellite operators.*
- *The results show that the proposed method provides favorable values in communication satellites orbit determination.*
- *The utilization of GPS satellites is a promising approach for geostationary satellite orbit determination. The communication satellites operators can utilize the GPS-based orbit determination with its benefits.*

Graphical Abstract

The average 3D position and velocity differences between actual orbit and proposed method results are 20.758 m and 0.447 cm/s, respectively. The results, therefore, indicate that the communication satellites' orbit can be accurately determined with GPS-based range measurement.



(a) **(b)**

Figure 1. (a) Sat1 detailed position differences (b) velocity differences, in radial, in-track and cross-track direction for 24 hours.

Aim

The purpose of this study is to propose a GPS-based range measurement via space-born receivers onboard communication satellite platforms for precise orbit determination of geostationary satellites. Thus this research investigates how proposed method can be applied to obtain reliable and sustainable results. The analysis was performed to find out the accuracy and validity of the proposed method.

Design & Methodology

The measurement data was collected via onboard space-born receiver and processed with proven sequential process (SP) Kalman filter method. Flight proven satellite dynamic model and orbit propagation approach were selected for calculation. The results were compared with actual orbital parameters using root mean square error (RMSE) and average deviation (AvDev).

Originality

The validity of the reliable and sustainable usage of the proposed method is original, and the method new approach in communication satellite orbit determination.

Findings

The presented results show that radial, in-track, cross-track, and 3D position and velocity differences are minimal and meet perfectly operational requirements. Therefore, the usage of onboard GPS receivers proposes decent performance for orbit determination with economic and operational benefits.

Conclusion

The communication satellite operators can utilize onboard satellite space-born receiver-based measurement data for precise orbit determination with benefits of low cost, low operation, autonomous orbit determination capability, and independence from TCR and payload.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

GEO Satellite Orbit Determination Using Spaceborn Onboard Receiver

Araştırma Makalesi / Research Article

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ABSTRACT

The use of space-born GNSS receiver onboard geosyncronous communication satellite is an effective alternative orbit determination technique compared to traditional methods, although the communication satellite operator and manufacturers need some proof. In this study, GPS-based range measurement via space-born receivers' onboard communication satellite platforms was proposed for precise orbit determination of geostationary satellites. Thus this research investigates how proposed method can be applied to obtain reliable and sustainable results. The analysis was performed to find out the accuracy and validity of the proposed method. Moreover, the results were compared with the simulation of four satellites' orbital parameters at different orbital slots. The sequential process (SP) Kalman filter method was chosen to process the measured data. The processing method was kept the same for all analyses to investigate the gathered measurement data effects. The results show that the average position differences between the determined and actual orbit are 17.613 m, 13.637 m and 14.998 m, for in-track, cross-track, and radial direction. The average in-track, cross-track, and radial velocity differences are 0.339 cm/s, 0.160 cm/s, and 0.066 cm/s respectively. The results show that the proposed method is approved in communication satellites orbit determination. The utilization of GPS satellites is a promising approach for geostationary satellite orbit determination. The communication satellites operators can utilize the GPS-based orbit determination with its benefits.

Keywords: orbit determination, gnss based orbit, communication satellites orbit, orbit determination performances.

Yere Eşlenik Uydularda Tümleşik Uzay Tabanlı Alıcılar Kullanarak Yörünge Belirleme

ÖZ

Haberleşme uydularına tümleşik konum belirleme uydusu alıcıları ile yörünge belirleme yöntemi, uydu işletmecileri ve üreticileri tarafından tam olarak kabul edilmiş olmasada geleneksel yöntemlere alternatif etkili bir method olarak kullanılabilmektedir. Bu çalışmada haberleşme uydularının hassas yörünge belirleme operasyonu için uyduya tümleşik konum belirleme (GPS) alıcısı ile mesafe ölçümü önerilmiştir. Bu metodun güvenilir ve sürdürülebilir sonuçlar elde etmek için nasıl uygulanabileceği araştırılmıştır. Önerilen yöntemin geçerliliği ve hassasiyeti analiz edilmiştir. İlave olarak elde edilen sonuçlar farklı boylamlarda işletilen dört uydunun yörünge parametreleri ile karşılaştırılmıştır. Ölçüm verilerinin işlenmesi için sıralı işlemsel Kalman filtresi yöntemi seçilmiştir. Bu yöntem toplanan verinin etkisinin incelenmesi için tüm analizler boyunca değiştirilmemiştir. Gerrçek yörünge değerleri ile elde edilen sonuçlar arasındaki ortalama mesafe farkının, radyal, hareket yönünde ve hareket yönüne dik değerleri 14.998 m, 17.613 m, and 13.637 m dir. Ortalama radyal, hareket yönünde ve hareket yönüne dik hız değerleri ise sırasıyla 0.066 cm/s, 0.339 cm/s, 0.160 cm/s dir. Elde edilen sonuçlar önerilen metodun haberleşme uyduları yörünge belirleme operasyonunda kullanılabileceğini göstermektedir. Haberleşme uydusu operatörleri GPS tabanlı yörünge belirleme yöntemini diğer faydaları ile birlikte kullanabilirler.

Anahtar Kelimeler: Yörünge belirleme, konum belirleme yörüngesi, haberleşme uydusu yörüngesi, yörünge belirleme performansı.

1. INTRODUCTION

GEO (geostationary orbit) satellites are predominantly used in broadcasting, communication, remote sensing, navigation, and data transfer. One of the key operations of communication satellites is accurate orbit determination for the operators. The communication satellite's operators widely use single station tracking (azimuth, elevation, and range) and range-range types traditional orbit determination methods for their operations. The operator can achieve the orbit accuracy of 10 – 100 m level with traditional ground-based ranging, which meets almost all orbital requirements in the GEO mission. [1].

Global navigation satellite systems (GNSS), initially deployed to provide location and timing information for military and civil users. As of September 2021, there are four globally available GNSS. Those are the U.S. GPS (Global Positioning System), Russian Federation's GLONASS (Global Navigation Satellite System), China Republic's BDS (Beidou Navigation Satellite System, and the European Union's navigation satellites Galileo. The GNSS constellation's orbit is MEO (medium earth orbit) with several orbital planes. Galileo's system has 23222 km altitude and 14 hours 5 minutes' revolution period.

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Similarly, the GPS, the Glonass, and the BDS have 20180 km, 19130 km, 21150 km, altitude, and 11 h 58 min, 11 h 16 min, 12 h 38 min revolution period, respectively. The GNSS orbital periods are generalized as roughly 12 hours at an altitude of about 20000 km.

The research in the use of GNSS signals for communication satellite orbit determination is less, although there are some experimental projects to analyze the possibility and performances. However, in low earth orbit (LEO) orbit determination, there are many works and practical implementations. A major point of difference between LEO and geostationary (GEO) satellite GPS-based orbit determination is GNSS signal collecting geometry. In LEO, the space-crafts are inside the GNSS orbit like ground users, but in GEO, spacecrafts (satellites) are outside of the GNSS orbit and can receive signals from the other side of the earth. The GEO orbit is defined in this study as an orbit that has about 36000 km altitude, low inclination, and low eccentricity values.

Falcon Gold experiment was launched to determine power level of GPS signals at high orbital altitudes using a special sensor. The sensor collected and digitized the RF energy of GPS signals. The GPS data in the digitized signal is extracted and processed. The engineers acquired and assessed the data for potential utilization. The analyses provide confident results of GPS signal detection at altitudes around the geostationary orbit and delivers valuable information for future geostationary orbit usage of the signal [2].

The navigation on the earth can be utilized by gathering positioning, velocity, and timing services of GNSS. Similarly, navigation in space uses the same GNSS services. LEO (Low Earth Orbit) satellitesare located below GNSS orbit receive signals like users on the ground. However, the orbit above the GNSS orbit is another concept for navigation. The satellites at geosynchronous orbit are above the GNSS orbit and receive the navigation signal from the far side of the earth. The geostationary satellites' GPS receive antenna field of view for the main lobe is limited, and the reliability of signals for positioning and orbit determination are in question. The use of GPS receiver onboard communication satellite platform becomes a smart alternative method for orbit determination.

The use of GNSS space-born receivers for satellite orbit determination has interest due to possible reduction on-ground operations and economic reasons. However, the satellite manufacturers and operators have not fully accepted the use of GNSS in orbit determination. The GNSS system in satellite orbit determination needs some proof to convince the industry and the operators [3].

The use of GNSS in geostationary orbit must be evaluated in terms of performance. In this study, we describe the space-born receiver-based range measurement for orbit determination of geostationary satellite and discuss the validity of the results with four satellites' orbital parameters at different location.

The utilization of GNSS signals in space has exceptional challenges. The researchers have calculated a link budget of signal in many studies and performed analysis for orbit determination. The disadvantage of a geosynchronous mission is that space-born receiver altitude is higher than GNSS altitude; consequently, the navigation satellite constellation's geometric distribution is weak. The earth blocks most of the main lobe of signal emitted from GNSS [4], [5]. It is necessary to receive the side lobe signals to overcome the blocking situation and improve the geometric distribution [5]. In a navigation signal, the side lobe signals are about 20 dB less compared to main lobe signals; consequently, we need to improve the performance of space-born receivers [6], [7], [8]. Space-born receivers to determine the orbit of LEO became common recently. Various types of spaceborne GPS receivers developed around the world. US and the European Union manufacturers developed various space-born receivers to use onboard satellites. LEO performance of GPS receivers meets the expectations, and its geosynchronous orbit applications are investigated [5].

Several experimental works have been demonstrated for GNSS-based geosynchronous orbit determination. GOES-R (The Geostationary Operational Environmental Satellite-R) tests the spaceborne GPS receiver to determine the geo orbit [9]. Another spaceborne GNSS receiver named Mosaic has been implemented in the small GEO platform. The inflight performance shows that the signals acquisition is in operational range, and the position errors are acceptable [10]. Furthermore, there are several types of research for lunar missions and highly elliptical orbits. The researchers have investigated the feasibility of GNSS-based navigation for lunar missions. [11], [12], [13].

GNSS-based orbit determination is a challenging approach compared to conventional ground-based positioning. The formulation and solution of orbit estimation is not the difficulty of GNSS based approach, but the validation of the solution is an important step. The solution accuracy in precise orbit determination revolves around the data collecting method and processing technique. The classical least squares and Kalman filtering technique estimate orbital parameters at epoch.

The use of the Global Navigation Satellite System (GNSS) for geostationary earth orbit (GEO) determination has the advantages of low terrestrial station cost and the possibility of onboard automation. GNSS has been widely utilized for LEO satellite orbit determination. LEO satellites with onboard space-born receivers have been operated for different purposes of orbit determination [1], [14].

GPS processing algorithms take outer space conditions into account; however, orbit determination accuracy depends mostly on onboard clock errors rather than satellite motion models. GPS orbit determination accuracy is about 10-40 m for different types of onboard clocks [15].

Figure 1 shows the weak nature of the GPS signal for GEO satellites. The signal from the GPS satellites is blocked by the earth most of the time.

In addition to the blockage, the main lobe of the signal can be received for a short period of time. The spaceborne GPS receivers should be equipped with side lobe signal processing capability to overcome this problem.

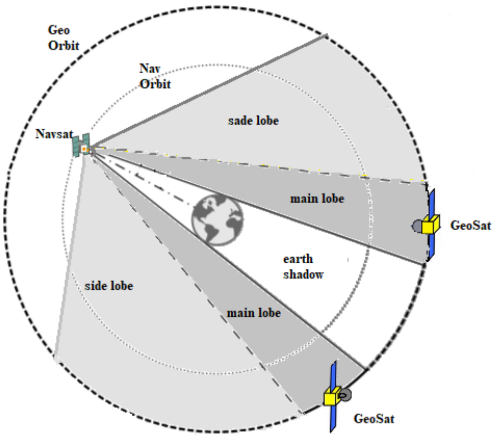

Figure 1. GPS signal main lobe, side lobe and the earth blockage seen from the satellites located at geostationary orbit.

Figure 2 shows that the GEO satellites are located above the altitude of the GPS satellites; consequently, their signal reception is only possible from the GPS satellites on the other side of the earth.

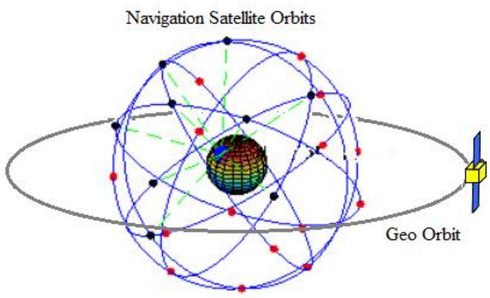

Figure 2. Geostationary satellites can receive the GPS signal only from the other side (far side) of the earth.

There are some studies to process GS, Galileo, Glonass, and BDS signals all together to improve orbit determination accuracy [3]. Those combo receivers can process the side lobe signal, which is typically 20 dB less than the signal's main lobe. The weights of the onboard satellite spaceborne receivers are about 1.2 kg, and the power requirements are around 30 Watts [16], [17]. The weight and required power of the GPS receiver have very little impact on a satellite mass and power budget as the communication satellite's dry masses are about 3500 kg and 10 kW, respectively. Therefore, the use of GPS receivers has the benefits of low cost and reduction of operations.

2. RANGE MEASUREMENT and ORBIT DETERMINATION METHOD

2.1. Measurement Models

In this study, the onboard spaceborne GPS receiver is assumed to be mounted on the communication satellite platform. Clear Acquisition (C/A) L1 signal pseudo-range measurements are performed between a visible GPS satellite and onboard satellite receiver.

C/A (clear/ acquisition) code pseudo-range in L1 frequency can be expressed in Equation 1,

$$\rho_c = \rho + c[\Delta t_{GPS}(t) - \Delta t_u(t)] \tag{1}$$

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

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

where x, y, z: postion of the geo satellite, $x_{GPS}, y_{GPS}, z_{GPS}$: GPS satellite.

$$t = t_{GPS} - \Delta t_{GPS} \tag{3}$$

$$\Delta t_{GPS} = a_{f0} + a_{f1}(t - t_{oc}) + a_{f2} + \delta_R^{GPS} \tag{4}$$

Equation 1's second term is the clock biases representing the combined clock offsets of the satellite and the receiver with respect to GPS time. Each GPS satellite has a different clock bias. GPS satellite clocks bias value is known and transmitted via a navigation message.

GPS user clock correction at epoch t is the user clock offset given by Equation 5.

$$c\Delta t_U = b_0 + b_1\Delta T + b_2\Delta T^2 + \delta_R^{USER} \tag{5}$$

where b_0, b_1, and b_2 are the user clock's bias, drift, and drift rate, ΔT: the elapsed time after the first measurement.

Both GPS satellite and user clock effects are calculated using the best available estimated state vector in the epoch. We considered clock biases to focus on the performance of receivers rather than the onboard clock errors on measurement data and its effects on-orbit determination accuracy in this work.

2.2. GEO Satellite Dynamic Model

In this work, the communication satellite dynamic model and the satellite position and velocity dynamics are expressed with respect to the J2000 Earth Centered Inertial (ECI) coordinate system. The X and Z axes point toward the mean vernal equinox and mean rotation axes

of the Earth on 1 January 2000, at 12:00:00.00 UTC (J2000= 2000, January 1.5 = JD –Julian date-2451545.0), in the J2000 system.
The satellites position and velocity vector can be expressed as $r = [x\ y\ z]^T$ and $v = [Vx\ Vy\ Vz]^T$ respectively without clock error consideration.

$$X_{orbit} = \begin{bmatrix} r \\ v \end{bmatrix} = [x, y, z, v_x, v_y, v_z]^T \quad (6)$$

2.3. Orbit Estimation Technique.

In this study, we proposed running the sequential process (SP) Kalman filter algorithm to estimate the satellites' orbit. This SP Kalman filter is robust, with easy implementation for applications in real-time. Moreover, the SP Kalman filter can be applied to nonlinear problems [5].
SP methods provide refined position and velocity estimation. The following approach was utilized to estimate orbit using the filter method. Since the onboard GPS receiver has got some clock errors the term b_0 added to the Equation 7.

$$\Delta X = A(t)X\Delta t + B(t)\Delta\beta \quad (7)$$

where;
A(t): nxn time dependent matrix (measurement data), *Δt*: time increment, *B(t):* nx3 time dependent matrix, *β*: Brownian motion
The calculated position and velocity vector are given by Equation 8-11.

$$X = (r, v, b)^T \quad (8)$$

$$r = (x, y, z)^T \quad (9)$$

$$v = (\dot{x}, \dot{y}, \dot{z})^T \quad (10)$$

$$b = (b_0, b_1, b_2)^T \quad (11)$$

where *x:* the satellites state vector, *r:* the satellites's position vector, *v:* the satellites velocity vectors, *b*: bias, drift, and drift rate of the receiver clock.
The solution of Equation 7 performed by utilizing Matlab codes and some built in libraries provide orbital elements of satellites. The results can be in various time and coordinate systems. These systems can be converted to each other. In this study classical orbital elements and UTCG were choosen because they have common usage among satellite operators.

2.4. Measured Pseudorange Data

The pseudo-range measurement data were obtained with the pseudo-range method for four communication satellites, and those data would be processed to determine the orbits of the satellites at geostationary orbit, as shown in Figure 3. In this method, range data with time tags are called observation data obtained from available GPS satellites. The collected data were pre-processed, and necessary adjustments such as biases were applied. A new data set was utilized to calculate the orbital parameters with the SP method. Finally, the results were checked and validated to prove the method.

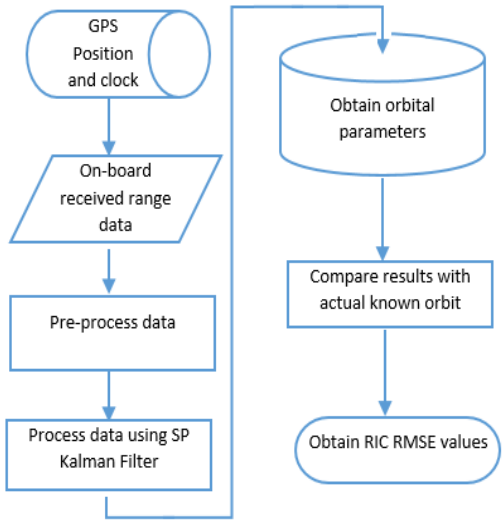

Figure 3. GPS based orbit determination flowchart used in this work.

Table 1. provides the range between geosynchronous satellite Sat1 and visible GPS satellites. PRNxx identifies GPS satellites that signal being received. The measurement was performed using CA L1 frequency of GPS satellites visible from Sat1 orbital location for a 24 hours' period by 10 minutes' step.
This measurement was performed simultaneously for four communication satellites. This study evaluates four satellites located at different GEO orbital slots.
The visible GPS satellites from Sat1 at 42.0 E location are shown in Figure 3 for 24 hours' period. The number of visible GPS satellites must be four or more to perform range measurement. There are enough GPS satellites to perform healthy range measurements.

Table1. Range measurement between visible GPS satellites and Sat1 satellite via L1 signal.

UTC	Satellite Name	CA Pseudo-range (m)
00:00:00	GPS-PRN12	67121563.12
00:00:00	GPS-PRN25	67594600.14
00:10:00	GPS-PRN12	67038.845.62
00:20:00	GPS-PRN12	66873392.42
…	…	…
23:40:00	GPS-PRN25	66779396.49
23:50:00	GPS-PRN25	67307409.34

Figure 4 shows that there are enough visible GPS satellites to perform pseudo-range measurement between visible GPS satellites and the GEO satellites. The Pseudo Random Noise (PRN) Code serves in GPS, for a satellite identification, ranging, and mitigation of reflection and interference effects. PRN shows GPS satellites that signal being receved in Figure 4

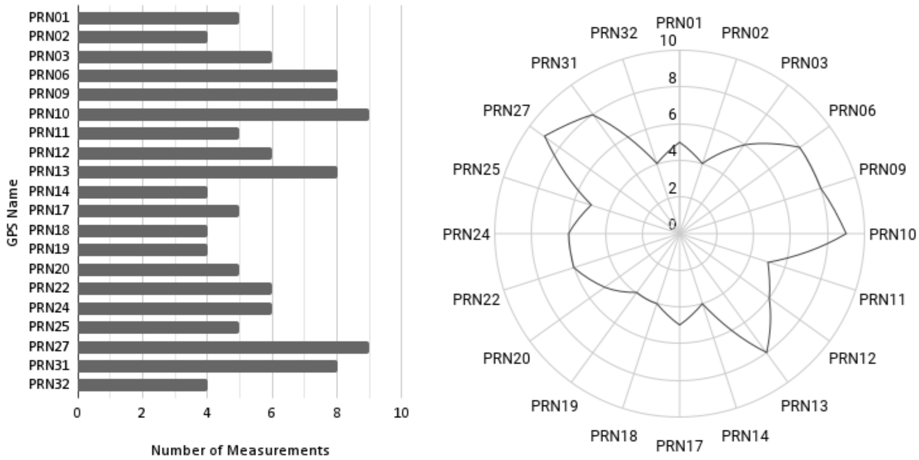

Figure 4. Number of visible GPS that are utilized for pseudo-range measurement for 24 hours from Sat1 onboard spaceborn receiver

3. RESULTS

This paper describes the feasibility of the use of a GPS receiver in observation data collection for communication satellite orbit determination. Although GEO satellites' altitudes are higher than GPS satellites and the GPS signals main lobe most of the time shadowed by the earth, still it is possible to utilize those signals for precise orbit determination of GEO satellites. The presented results show that the usage of GPS receivers proposes decent performance for orbit determination with economic and operational benefits.

Table 2 below shows the actual orbital parameters of Sat1, Sat2, Sat3, and Sat4 at epoch. The satellites in Table 2 are communication satellites with very low eccentricity and inclination values.

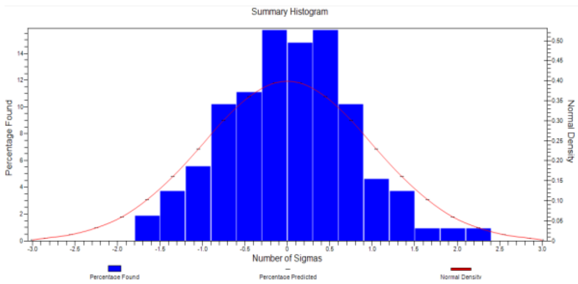

Figure 5. Summary of histogram for CA pseodorange for Sat1

The obtained results of the measurement residual and sigma values are shown in Figure 6. The values show residuals are usual for decent orbit estimation.

Table 2. Sat1, Sat2 Sat 3 and Sat4 actual orbital parameters at epoch.

	SMA (km)	Eccentricity	TA (deg)	Incl (deg)	RAAN (deg)	AoPer (deg)	Long (deg)
Sat1	42164.14	5.00E-05	0.0000	0.05	290.944	360.00	42.00
Sat2	42164.14	5.00E-05	0.0000	0.05	279.944	360.00	31.00
Sat3	42164.14	5.00E-05	0.0000	0.05	298.944	360.00	50.00
Sat4	42164.14	5.00E-05	0.0000	0.05	257.440	360.00	8.50

The sequential process (SP) Kalman filter method was run with gathered GPS range measurement data provided in Table 1 for satellites 4200 kg mass and 84 m^2 surface area. The residuals of the results provide information about the best fit of the calculated orbital data. So before comparing the obtained results and actual values, the residuals show the initial performance of the method.

The histogram of measurement in Figure 5 shows the flawless distribution in three-sigma confidence. Consequently, the pseudo-range measurement data file meets the necessary requirement to determine orbits.

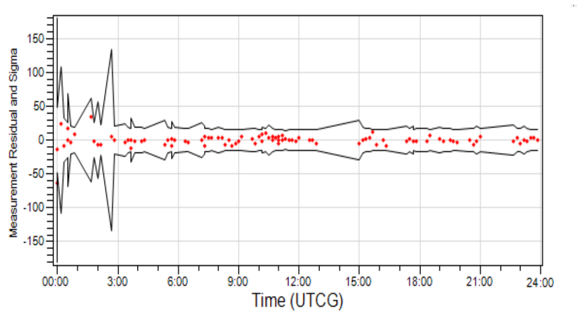

Figure 6. Sat1 measurement residuals and sigmas for 24 hours

Similarly, Figure 7 provides the distribution of residuals over a 24 hours' measurement period. The residual summary shows that the average value is -0.2899 and RMSE is 8.6813 for 109 measurements of Sat1. It can be concluded that the orbit estimation for geosynchronous satellites with GPS range measurements is very approving. Those favorable results emphasize that the method approach is worthy.

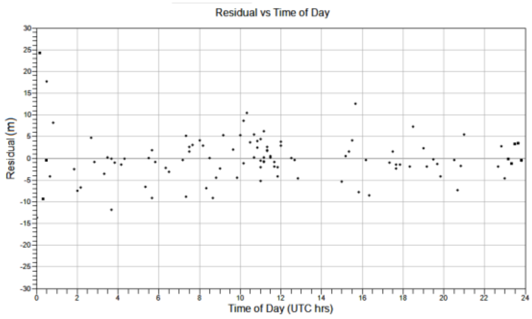

Figure 7. Sat1 range residuals for 24 hours

operational requirements are close to each other. Satellites in this work are GEO satellites and have very similar orbital characteristics to Eumetsat satellite and therefore these values are taken as reference target criteria in this study.

The sequential process (SP) Kalman filter run to analyze the performance of the proposed method. The differences between the determined orbit of Sat1, Sat2, Sat3, and Sat4 using GPS range data and actual orbital parameters are shown in Table 3. The results are compared based on root mean square error (RMSE). The average RMSE position difference of the four satellites are 14.998 m, 17.613 m, and 13.637 m in radial, in-track, and cross-track directions, respectively. The velocity differences are quite small and 0.066 cm/s, 0.339 cm/s and 0.160 cm/s in radial int-rack and cross-track direction. The results, therefore, indicate that the communication satellites' orbit can be accurately determined with GPS-based range measurement.

In the literature, the test flight obtained position and velocity errors during a day vary from 15 to 20m and from 0.014 to 0.018 m/s, respectively. The GPS signal characteristics, position dilution of precision (PDOP), carrier-to-noise ratio density (C/N0), availability, and observation quality affect the results [5], [19]. The results obtained in this research and test flight results are compatible.

Table 3. GPS and simulation position and velocity RMSE differences of four communication satellites at different orbital slots for 24 hours period.

	Position Differences (m)				**Velocity Differences (cm/s)**			
	Radial	**Intrack**	**Crosstrack**	**3D**	**Radial**	**Intrack**	**Crosstrack**	**3D**
Sat1	17.620	24.588	15.218	33.862	0.440	0.460	0.1551	0.655
Sat2	16.087	23.725	13.157	31.540	0.663	0.488	0.1385	0.835
Sat3	12.394	11.358	17.375	24.177	0.771	0.190	0.2127	0.822
Sat4	13.890	10.782	8.799	19.662	0.780	0.219	0.1325	0.821

Eumetsat orbit determination accuracy requirement is 1500 m, 500 m, and 50 m, in in-track, cross-track, and radial direction, respectively [18]. Similarly, velocity accuracy requirement is 100 cm/s, 10 cm/s and 1cm/s for in-track, cross-track and radial direction. Eumetsat GEO satellite public requrements mentioned above are taken as target criteria because Eumetsat is one of the leading operator in this industry and the satellite operators'

Figure 8 shows Sat1 detailed position differences for a 24 hours' period between the proposed method and actual orbit in radial, in-track, and cross-track. It is clear that after collecting the measurement data for 12 hours, that

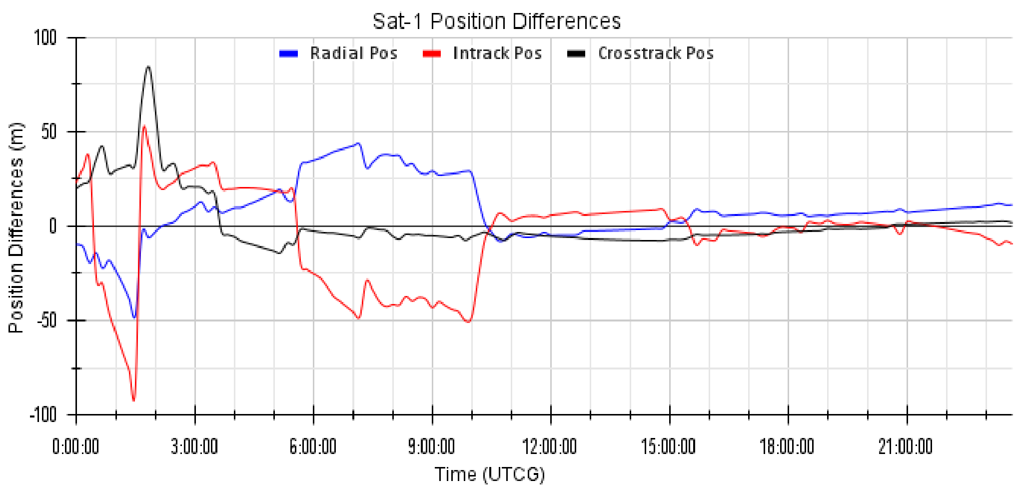

Figure 8. Sat1 detailed position differences in radial, intrack and crosstrack direction for 24 hours.

is the half of the revolution period, the differences become very small. That's why it can be concluded that determining orbital parameters using GPS is in line with actual orbital parameters.

Figure 9 shows Sat1's radial, in-track, and cross-track velocity differences between the proposed method and actual values.

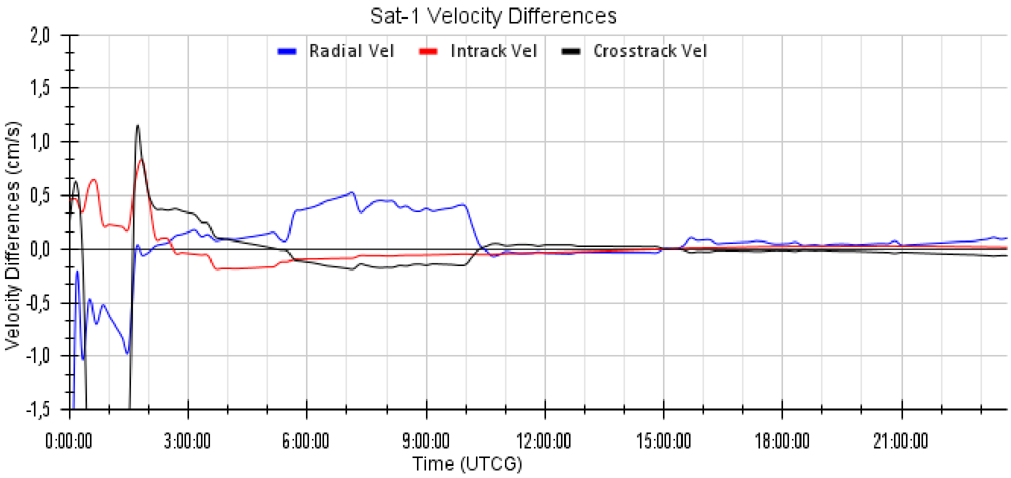

Figure 9. Sat1 detailed velocity differences in radial, intrack and crosstrack direction for 24 hours

The results are in the order of 0.3 cm/s, which is quite a good value. The ripple in the graph decreased as time increased and became very smooth after roughly 10 hours. The results are less than the targeted value. Therefore, it can be concluded that the proposed method provides a very good estimation of velocity.

Tablo 4. GPS and simulation position and velocity average deviation of four communication satellites at different orbital slots for 24 hours' period

	Position Differences (m)				**Velocity Differences (cm/s)**			
	Radial	**Intrack**	**Crosstrack**	**3D**	**Radial**	**Intrack**	**Crosstrack**	**3D**
Sat1	10.933	18.210	9.613	23.314	0.181	0.205	0.0839	0.287
Sat2	12.596	15.961	8.496	22.037	0.215	0.274	0.0825	0.358
Sat3	12.394	11.358	17.375	24.177	0.771	0.190	0.2127	0.822
Sat4	8.909	8.056	6.170	13.504	0.287	0.117	0.0798	0.320

Table 4 provides four communication satellites radial, in-track, cross-track, and 3D differences between the proposed method and the actual values. Table 4 shows the average deviation of data, but Table 3 shows the RMSE of data. The average 3D position differences are 20,758 m, and the average 3D velocity differences are 0.447 cm/s. The results meet general geosynchronous satellite operators' requirements

The proposed GPS-based range measurement method benefits low station costs, the possibility of autonomous orbit determination, and independence from the satellites telecommand, tracking and ranging (TCR), and payload system

4. DISCUSSION

The use of GPS-based range measurement via onboard geostationary satellites spaceborne GNSS receiver are proposed, and related estimated orbit accuracy are discussed in this work. There are few studies on geostationary satellite orbit determination, and most of them are in the experimental phase. The communication satellites manufacturers and operators are reluctant to use GPS-based orbit determination because of not having enough evidence for the performances. This study validated space-born receiver measurement data used for geostationary orbit determination. The proposed method orbit determination performance is very approving in position and velocity values. The differences between the proposed method and actual orbit and other traditional methods are too small and very promising. The results are very close to some other research [20], [21].

Moreover, the weight and required power of the GPS receiver have minimal impact on a satellite mass and power budget as the communication satellite's dry masses are typically about 4000 kg and 10 kW, respectively. According to the study's outcome, the communication satellite operators can utilize onboard satellite space-born receiver-based measurement data for precise orbit determination with benefits of low cost, low operation, autonomous orbit determination capability, and independence from TCR and payload.

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

AUTHORS' CONTRIBUTIONS

İbrahim ÖZ: Performed the experiments, analyse the results, did the literature research and wrote the manuscript.

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