KOMPSAT-1 Satellite Orbit Control using GPS Data

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Abstract

The Global Positioning System (GPS) is becoming more attractive navigation means for LEO (Low Earth Orbit) spacecraft due to the data accuracy and convenience for utilization. The anomalies such as serious variations of Dilution-Of-Precision (DOP), loss of infrequent 3-dimensional position fix, and deterioration of instantaneous accuracy of position and velocity data could be observed, which have not been appeared during the ground testing. It may cause lots of difficulty for the processing of the orbit control algorithm using the GPS data. In this paper, the characteristics of the GPS data were analyzed according to the configuration of GPS receiver such as position fix algorithm and mask angle using GPS navigation data obtained from the first Korea Multi-Purpose Satellite (KOMPSAT). The problem in orbit tracking using GPS data, including the infrequent deterioration of the accuracy, and an efficient algorithm for its countermeasures has also been introduced. The reliability and efficiency of the modified algorithm were verified by analyzing the effect of the results between algorithm simulation using KOMPSAT flight data and ground simulator.

Key Word : KOMPSAT, GPS, Ephemeris, Orbit Control

Introduction

The orbit control of KOMPSAT is mainly performed based on the data that the GPS receiver provides. The GPS receiver is capable to track the signal from GPS satellites and achieve 3-dimensional position fix within less than 30minutes if it was properly initialized with all the input data that are necessary[1]. KOMPSAT can continuously read out the right position of itself from the receiver unless any anomaly happens. Although ranging by ground station would inevitably be involved when KOMPSAT is in LEOP(Launch & Early Operation) or emergency, there is no need to upload additional commands for orbit control once if the GPS receiver acquires the position fix. This is a great advantage that can effectively reduce the workload on ground and performs more precise orbit control than ranging does. The GPS information shows less than 120m position errors (2σ) in any mission phase and can be an effective means for an LEO earth observation satellite like KOMPSAT [2].

Despite the accurate information and convenience GPS provides, infrequent deterioration and loss of position fix has been a burden of the ground station operation throughout the KOMPSAT LEOP. This symptom could impact on the on-board ephemeris propagation of KOMPSAT and prevent it from using GPS information any more eventually. If the spacecraft ignores several frames of GPS data because of their accuracy, it will lead permanent loss of GPS lock due to the nature of tracking algorithm. The intervention of ground station would be inevitable to avoid the accumulation of position errors when the loss of GPS lock happens[3]. The upgrade or modification of the tracking algorithm

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was necessary to overcome the infrequent deterioration of GPS information and to assure the spacecraft safety.

In this paper, the characteristics of KOMPSAT GPS information and the problem of data tracking are discussed in chapter 2 and chapter 3, respectively. In chapter 4, a new tracking algorithm that effectively improves the performances is presented with the simulation results. It is followed by chapter 5-the conclusions.

Characteristics of KOMPSAT GPS Information

The KOMPSAT GPS receiver provides very accurate information for the time, velocity and position of the spacecraft, which are essential for the operation. The infrequent deterioration of the GPS information, however, had restricted its utilization so far. It may be caused by the rapid turnover of GPS satellites, which occurs when the spacecraft navigates more than 7km/sec speed in space. The receiver sometimes could not secure 4 GPS satellites, which are the minimum number of satellites for 3-dimensional position fix so that the receiver loses its accuracy as a result. Even when the receiver contacts more than 4 GPS satellites, the accuracy drops could be observed, but it depends on the geometrical distribution of GPS satellites[3]. The DOP is quite useful when evaluating the accuracy of GPS data, and the receiver usually takes PDOP (Position Dilution Of Precision). Fig. 1 shows the DOP distribution of KOMPSAT GPS data.

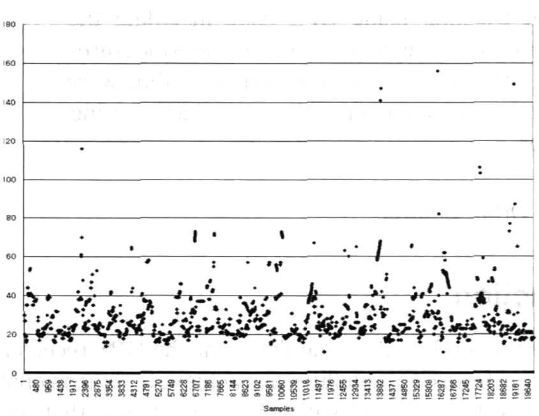


Fig. 1. DOP Distribution

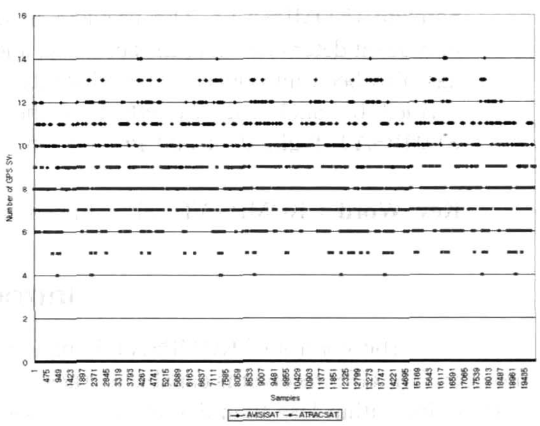


Fig. 2. Visible & Tracked GPS satellites

KOMPSAT downlinks the DOP status once in every 16 seconds. Although every variation of DOP number could not be tracked, the pattern is obviously worse than that of ground test. In the KOMPSAT ground test, the receiver showed quite stable DOP status that mostly stayed below 2.0. The "0" DOP means that the receiver lost 3-dimensional position fix in the Fig. 1[1].

Generally, the number of GPS satellites that can be tracked is reduced near earth pole in the KOMPSAT telemetry. The accuracy drops, however, could occur regardless of the spacecraft position. Fig. 2 displays the number of GPS satellites tracked by the receiver in comparison with the number of visible satellites. The composition of GPS satellites tracked is changed too often as shown in Fig. 2, which impacts the stability of the receiver output.

It is important to analyze the GPS data trends for the spacecraft operation when the deterioration happens. When the GPS receiver losses 3-dimensional fix, the GPS output, especially velocity portion, drifts to someplace else gradually. It, then, suddenly jumps to where it is supposed to be, when position fix is reacquired. This usually lasts for a short time - less than 10 seconds or little more, but the jump is sometimes relatively long, with which any tracking algorithm can hardly bear. It happens throughout the entire orbit and the occurrence is highly unpredictable. Fig. 3 shows a good example of the GPS data trend, when position fix is lost.

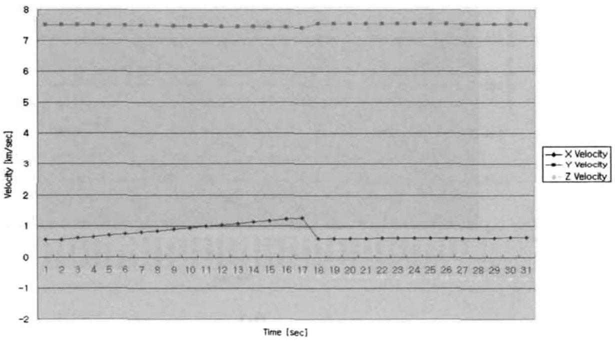


Fig. 3. GPS velocity output when position fix is lost

Table 1. Configuration of GPS receiver

Items	Values used
Mask Angle	-5, 0, 10
DOP Hysteresis	1.0, 6.0
2D DOP Threshold	20.0
Position Fix Algorithm	n-in-view, best-of-4

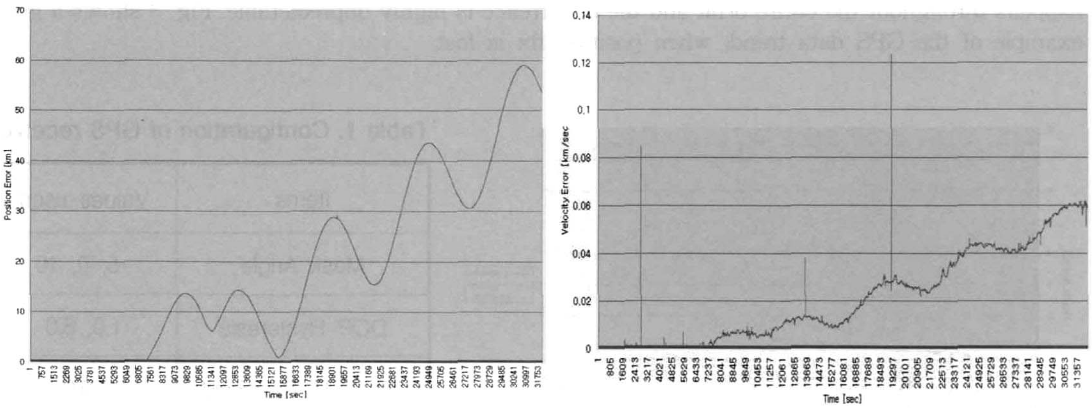
The status of the GPS receiver is one of the major factors that determine the accuracy of its data. It is required to set the receiver to minimize the frequency of GPS satellites turnover. The items that the user can set for the GPS operation are mask angle, the type of position fix algorithm, DOP hysteresis and 2D DOP threshold. Table 1 lists the values for each item, which were used in the on-orbit test.

The DOP numbers is obviously related to the mask angle which can be assigned by ground command. The lower mask angle gives the wider field-of-view which assures the better DOP number. The increase of the visible GPS SV(Space Vehicle)s, however, will cause too frequent turnovers that affect the stability of GPS measurements. The mask angle needs to be optimized through on-orbit test. The DOP hysteresis enables that the receiver compares the closeness of DOP for all combinations of visible GPS satellites when DOP hysteresis is lower than the current DOP. Higher DOP hysteresis can prevent the receiver from rapid turnover theoretically. To avoid using of erroneous GPS data when the deterioration happens, 2D DOP threshold can be assigned to force the receiver give up the 3D fix when the current DOP is higher than 2D DOP threshold number. The receiver will then output 2D data instead of 3 dimensional output. When the receiver is commanded to use n-in-view algorithm, it will use up to 6 GPS satellites for position fix out of the 10 tracked. The best-of-4 mode enables the receiver to use the best 4 GPS SVs which have stronger signal level, no matter how many GPS SVs are being tracked, to avoid any negative influence from weaker signal[1].

Through the on-orbit test, 0 degree mask angle and 6.0 DOP hysteresis under the n-in-view algorithm have given better results, but no significant improvements were observed. The receiver still experienced the loss of 3D fix and occasional deteriorations which disturbed the stability of GPS data.

KOMPSAT Orbit Control

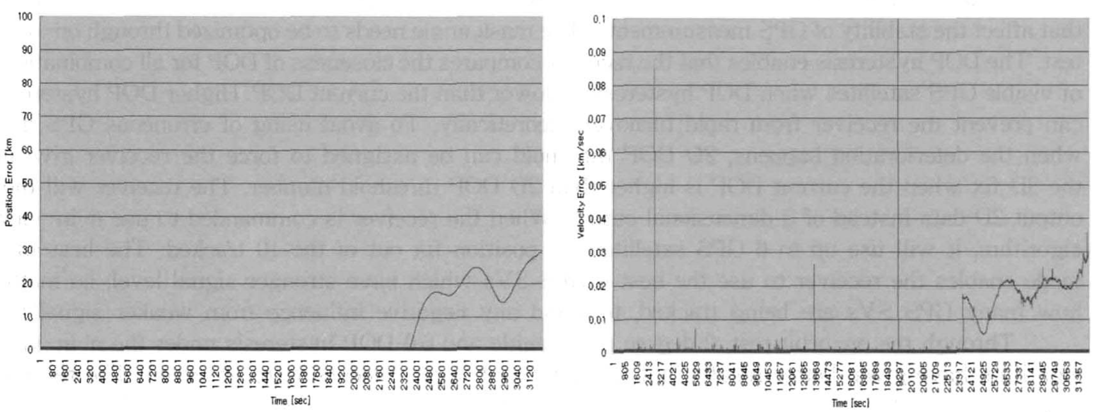
The KOMPSAT uses GPS position and velocity data for its orbit control only when the GPS data are available and reliable. The simple ephemeris propagator, located in one of the KOMPSAT processors, was involved to justify the incoming GPS information including XDOP, the status of 3-dimensional fix and position data. The tracking algorithm compares the GPS position and velocity to the values which the ephemeris propagator calculates based on the position and velocity data just a second ago and then uses them for orbit control if the differences are within the range fixed by ground station.



(a) (b)

Fig. 4. RSS Error of (a)Position & (b)Velocity (limit: position 1km, velocity 2m/sec)

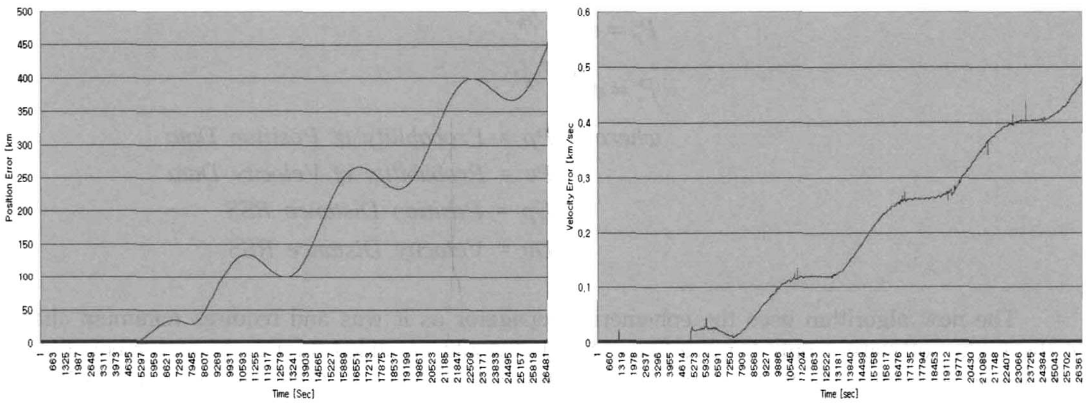
It has been frequently observed that the output data of the GPS receiver were sometimes getting relatively poor and they became less reliable as stated above. Although the period was usually short, some excessive errors of velocity data could cause the loss of GPS lock in the propagator during that time. Once it rejects GPS data because of their accuracy, it is not guaranteed to regain the GPS lock, even though the GPS data fully recover the required accuracy. Fig. 4 shows the position and velocity differences between GPS data and the propagator estimations, and well describes how the propagator is losing the GPS lock when the allowable error values are 1km for position and 2m/sec for velocity, respectively.



(a) (b)

Fig. 5. RSS Error of (a) Position & (b) Velocity (limit: position 6km, velocity 6m/sec)

Fig. 5 also displays the position and velocity differences when the position limit is 6km and the velocity limit is 6m/sec, respectively. The ephemeris propagator only can buy several minutes more by expanding the acceptable range, consequently. There is not a significant improvement even when the velocity limit is exceptionally increased to 20m/sec as shown in Fig. 6. A higher limit for velocity data can cause more differences in a short period due to the huge initial errors of velocity components that have been accepted in the moment of break off, and it will surely make the situation worse. The analysis shows that the reliable ephemeris propagation based on GPS data cannot be achieved only by controlling the acceptable error limits.



(a) (b)

Fig. 6. RSS Error of (a) Position & (b) Velocity (limit: position 6km, velocity 20m/sec)

New Tracking Algorithm

It is not possible to replace the whole flight software of KOMPSAT since it is in operation on-orbit. The partial patch is the only method to be considered. The patch of flight software is quite limited by the vacant memory space and processor throughput. Any sophisticated tracking algorithm that has been proven on ground cannot be applied to KOMPSAT directly because of it size and computational load. The new algorithm should require minimum modification of the flight software and throughput to meet the requirement in patch process.

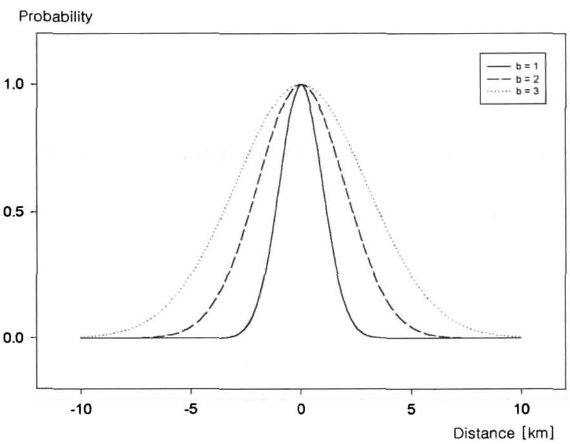


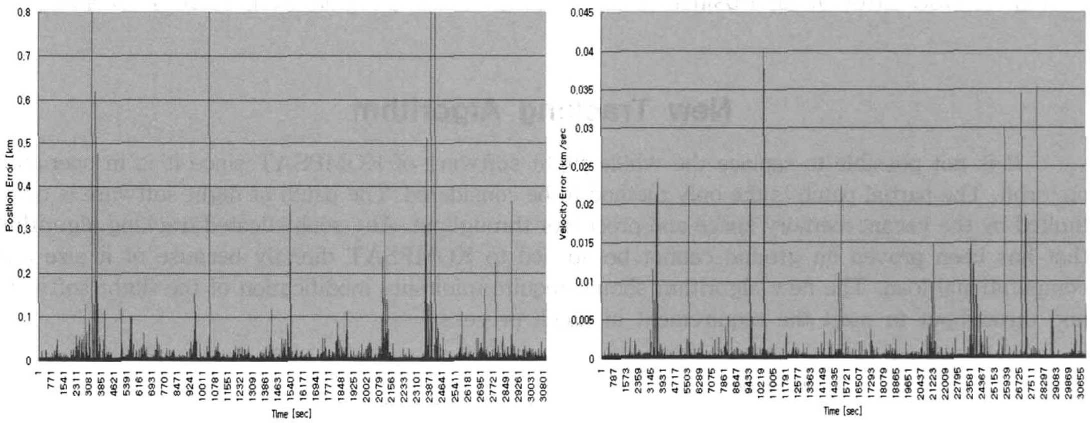
Fig. 7. Gaussian Fitting Curves used

In this paper, a simple algorithm that associates the probability of measurement accuracy based on a Gaussian fit is proposed. The new tracking algorithm assigns the suitable weight calculated from the Gaussian covariance of estimated point to each measurement and updates the spacecraft position and velocity by the measurement distances from the estimated points, which were already multiplied by their weights. Fig. 7 shows the Gaussian fit curve that has been used for the evaluation of the algorithm. The equations used for the Gaussian curve are listed in equation (1).

$$P_P = e^{-0.5(D_P/b)^2}$$
$$P_v = e^{-0.5(D_v/b)^2} \qquad (1)$$

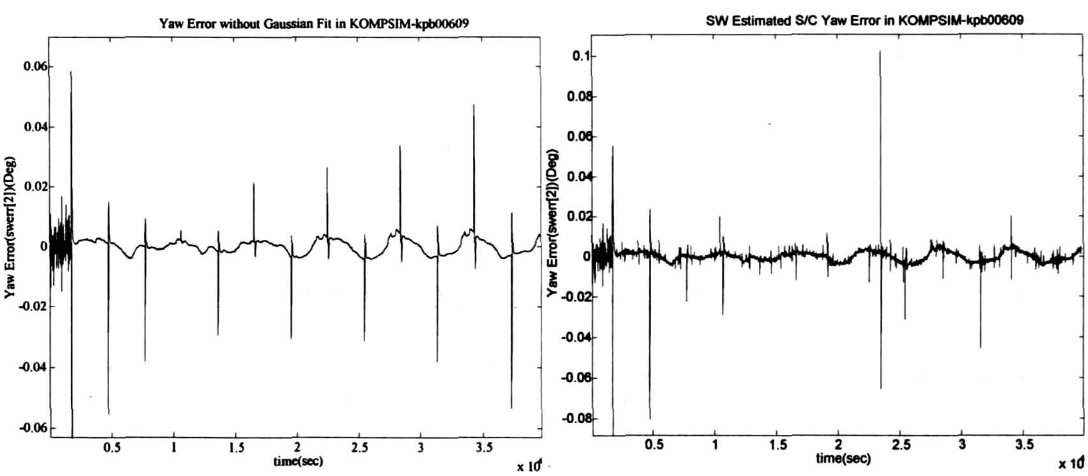
where: *Pp* = *Probability of Position Data*
Pv = *Probability of Velocity Data*
Dp = *Position Distance RSS*
Dv = *Velocity Distance RSS*

The new algorithm uses the ephemeris propagator as it was and requires minimum change of the flight software - only 6 more lines of codes would be added for this improvement. For the purpose of evaluation, the flight software was patched to provide the GPS position and velocity data every second and the related software modules were rarely modified for the adoption of the algorithm and ground use.



(a) (b)

Fig. 8. RSS Error of New Algorithm Tracking (a) Position & (b) Velocity



(a) (b)

Fig. 9. Yaw Error (a) without GPS (b) with GPS

The simulation results are pretty encouraging with the expected performances. It has never lost the GPS lock during the two weeks of evaluation period despite the accuracy drops. Fig. 8 displays the tracking results of the proposed algorithm when the GPS data are not reliable.

Another simulation using the KOMPSAT simulator has also been done which presented no significant disturbance in spacecraft attitude with the good performance of the modified propagator. There was no influence to the spacecraft attitude in roll and pitch direction when the GPS data are used. In yaw direction, high frequency jitter was induced due to the error of the GPS data as shown in Fig. 9. The amplitude of jitter is quite small and it is within the KOMPSAT requirement. The high spikes of Fig. 9 were generated by the update of the Fine Sun Sensor data near earth pole. The peaks of spikes were increased in Fig.9 (a) due to the loss of GPS lock.

Conclusions

GPS is getting widely applied in space since it can provide very accurate navigation solution. It, however, is quite limited in use due to infrequent deterioration and loss of position fix. This imperfect operation could impact spacecraft normal operation as seen in KOMPSAT case. The possibility of anomaly should be thoroughly reviewed from the design phase for any space-born GPS applications.

The proposed algorithm shows good performance and it can be one of the effective solutions when the deterioration of GPS data happens. The simulation was done with using real flight data, and proved the capability and reliability of the new algorithm. The use of the GPS noise matrix, instead of a simple Gaussian curves, can be considered for better results.

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