J. Astron. Space Sci. 26(4), 635–642 (2009) [Technical paper]

Implementation and Test of the Automatic Flight Dynamics Operations for Geostationary Satellite Mission

Sangwook Park[1], Young-ran Lee[1], Byoung-Sun Lee[2†], Yoola Hwang[2], and Javier Santiago Noguero Galilea[3]

[1]Ground Systems Division, Satrec Initiative, Daejeon 305-811, Korea
[2]Satellite Control and Navigation Research Team, ETRI, Daejeon 305-700, Korea
[3]GMV Aerospace and Defense, S. A., E-28760 Madrid, Spain
E-mail: parksw@satreci.com

(Received August 20, 2009; Accepted October 19, 2009)

Abstract

This paper describes the Flight Dynamics Automation (FDA) system for COMS Flight Dynamics System (FDS) and its test result in terms of the performance of the automation jobs. FDA controls the flight dynamics functions such as orbit determination, orbit prediction, event prediction, and fuel accounting. The designed FDA is independent from the specific characteristics which are defined by spacecraft manufacturer or specific satellite missions. Therefore, FDA could easily links its autonomous job control functions to any satellite mission control system with some interface modification. By adding autonomous system along with flight dynamics system, it decreases the operator's tedious and repeated jobs but increase the usability and reliability of the system. Therefore, FDA is used to improve the completeness of whole mission control system's quality. The FDA is applied to the real flight dynamics system of a geostationary satellite, COMS and the experimental test is performed. The experimental result shows the stability and reliability of the mission control operations through the automatic job control.

Keywords: satellite orbit, flight dynamics, mission control, automation, COMS

1. Introduction

The Flight Dynamics System (FDS) generates the orbit control data to carry out satellite operation. The operator of FDS takes the responsibility to distributing the flight dynamics data to other mission control system. These operations have to be repeated at a defined time interval. In addition, FDS is periodically received new data to be processed from the external systems. Moreover, those repeated job demands the careful attention to execute flight dynamics tasks. Even though the FDS operator has a good experience, the operator could make an omission of tasks that should be done in the specific time. Or the one may cause a critical error to whole mission control system by setting the parameters with wrong values. Especially, in the case of geostationary satellite mission control system that has connectivity with the satellite in 24 hours a day, a stable mission control operation is essential. Therefore, the autonomous system is required to help the operator's repeated and tedious manual jobs and to increase the usability of the system.

[†]corresponding author

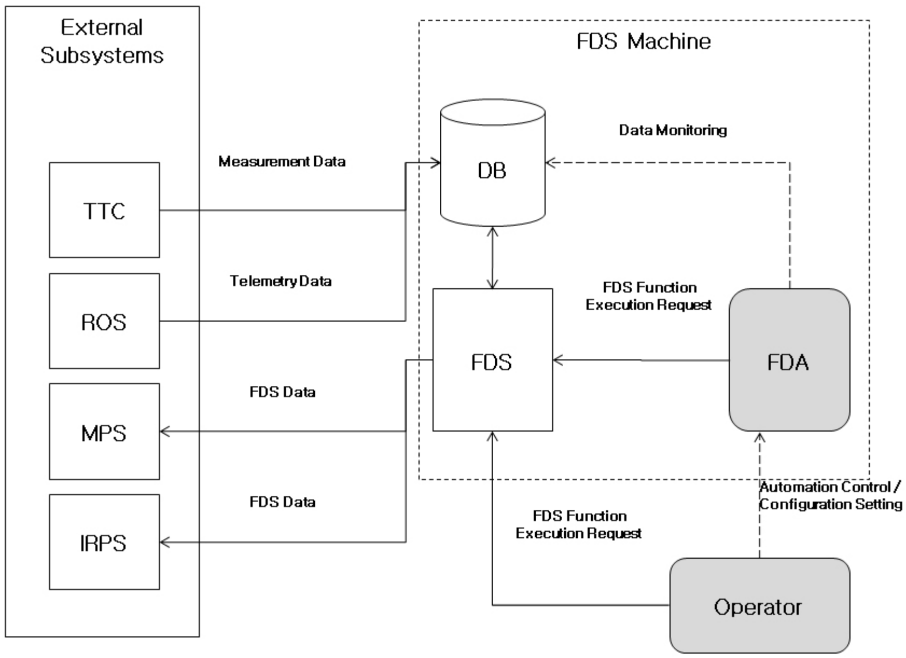

Figure 1. Architecture of Mission Control System and FDA.

Korea has a plan to operate Communication, Ocean and Meteorological Satellite (COMS) which is a geostationary satellite. The COMS Satellite Ground Control System (SGCS) have been developed and performed the system test to prepare the real operation. FDS has the capacity to generate the dynamics result in the various simulation environments to provide the functional validity and the performance of the COMS SGCS. The COMS SGCS consists of the five subsystems, such as Flight Dynamics System (FDS), Mission Planning System (MPS), Real-time Operations System (ROS), Telemetry, Tracking and Command system (TTC), and COMS Simulator Subsystem (CSS) (Lee et al. 2008b). Among other satellite mission control system, the FDS have to provide precise orbit elements, predicted orbit information and predicted event information at a certain period, and satellite status information to other systems.

As a previous work, automation of the routine flight dynamics operations including orbit determination and orbit prediction has been successfully implemented and tested for the low earth orbit satellite operations of the KOMPSAT series satellites (Lee et al. 2008a). Lee et al. (2009) defined and designed the Flight Dynamics Automation (FDA) system for the geostationary satellite operations in order to provide the flight dynamics functionality in autonomous way. Based on the previous work, the implementation of the designed automation system is described and the experimental test result for the geostationary satellite flight dynamics operations are shown in this paper. The developed FDA supports the operator's repeated tasks and helps to prevent the mistakes of the manual handling. It also provides a job scheduling at the predefined time or the reserved events. Therefore the developed FDA offers the efficiency and stability for the operator's manual tasks and the maintainability of the mission controls during the operator's absences.

The FDA processing procedure is based on the operator's operation scenario, so the job schedul-

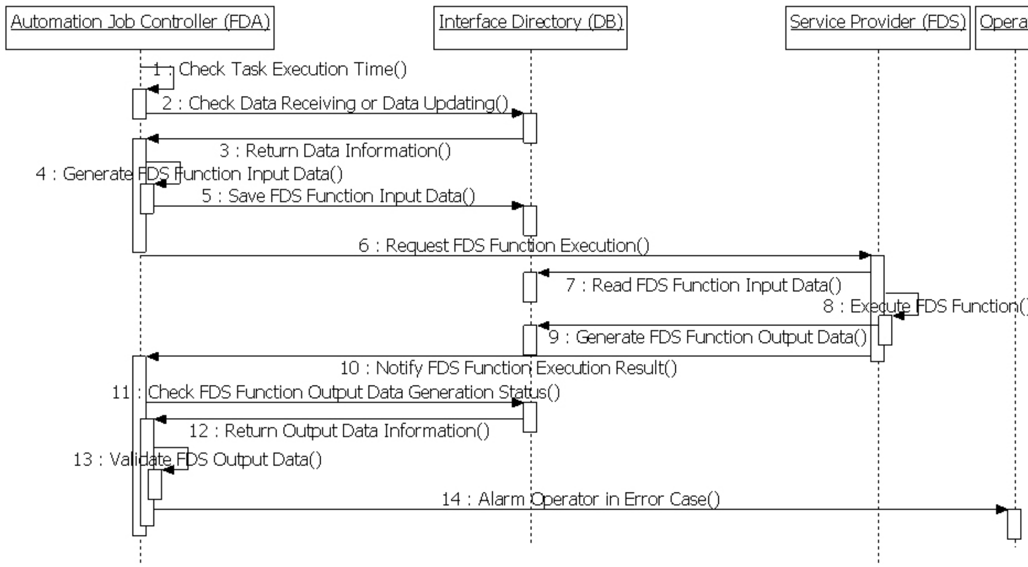

Figure 2. Processing procedure of FDA.

ing parameters are registered according to the operation scenario of each task. Moreover, FDA has the validation checking for input data which is transferred from other system and the result which are generated by FDS. If the result of FDS operation is not valid, then FDA alerts the operator and holds up the proceeding of further automation task such as FDS output data distribution. The implementation is described in section 2 and the result is described in section 3, the conclusion is followed in section 3.

2. Implementation of the Flight Dynamics Automation

2.1 System Architecture of Flight Dynamics Automation System

FDA can be installed in the same computer which has the FDS as a plug-in fashion. The FDS receives the ranging and tracking data (measurement data) which is used for orbit determination from TTC, the telemetry data which is used for fuel accounting from ROS. In addition the predicted orbit data transferred to MPS and Image Receiving and Processing System (IRPS). Although the FDS has many interfaces with the other subsystems, FDA has no interfaces with the other subsystems. The other mission control subsystems such as TTC, ROS, MPS, and the IRPS, have no need to know the FDA. The all interfaces between subsystem and the external system are performed through FDS as defined in the operation concept. FDA only controls the FDS like the operator. Figure 1 shows the architecture of the mission control system and FDA. The detailed descriptions for the design of FDA are shown in Lee et al. (2009).

2.2 Processing Procedure of Flight Dynamics Automation System

FDA is connected to the interface directory of the FDS. FDA periodically monitors the interface directory whether new data is arrived from other subsystem or not. If new input data is arrived, then

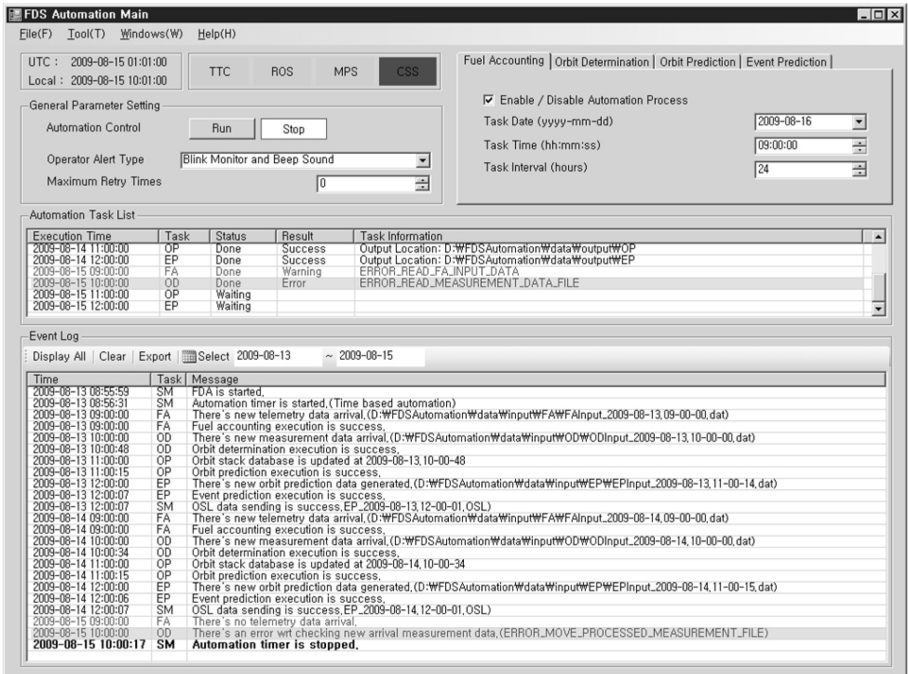

Figure 3. Main Graphical User Interface of COMS FDA.

FDA registers the required tasks in the autonomous job schedule and activates the schedule at the pre-defined time. The Figure 2 shows the operation procedure between FDA and FDS. FDA works as job controller while FDS acts like the service provider. If FDS finished the required services, then FDA validates the processing result. The FDA validation is the checking of the FDS generated message which is success or fail. The whole job sequences and the validated information are logged in detail. The Figure 2 describes the general working scenario between FDA and FDS. The job control is activated according to the external event such as data transferring from other systems or at the reserved time interval.

2.3 Graphical User Interface of Flight Dynamics Automation System

FDA does not require the interaction of FDS operator in normal case. However, in the case of exceptional or error occurred, FDA shows the warning message and alarming to the operator for the appropriate reactions. Moreover, all performed tasks are logged to support history analysis and system validation. Figure 3 shows the main GUI of FDA for COMS FDS. It consists of the parameter setting, logging and scheduled tasks windows. Four panels in upper-left corner of the FDA main GUI present network connectivity among Telemetry, Tracking and Command Subsystem (TTC), Realtime Operations Subsystem (ROS), Mission Planning Subsystem (MPS), and COMS Simulator Subsystem (CSS) in COMS Satellite Ground Control System (SGCS). Four tab pages in upper-right corner of the FDA main GUI have the same controls as in Fuel Accounting.

In the case of the exceptional or error case, according to ”Operator Alarm Type” in main GUI option setting status, FDA alarms to operator by blinking monitor or beep sound.

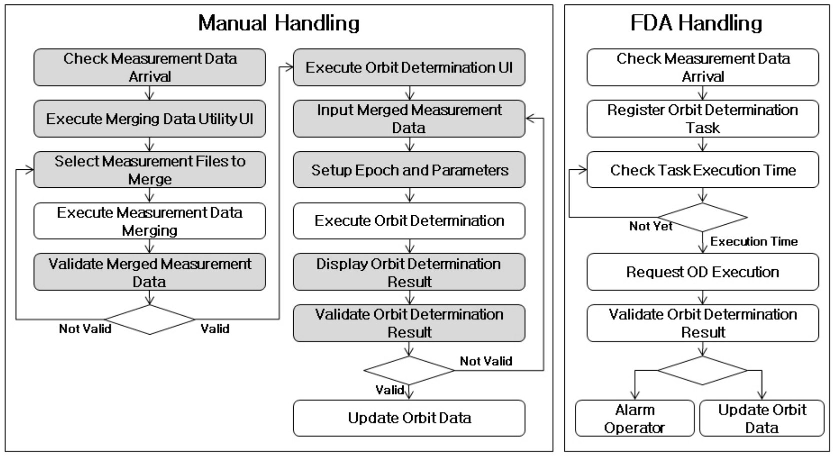

Figure 4. Comparison between manual handling in FDS and autonomous handling in FDA.

Table 1. Time comparison between manual and autonomous operations.

Task	Automation Result	Manual Result
Fuel Accounting (FA)	Elapsed Time: 1 sec	Elapsed Time: 48 sec
Orbit Determination (OD)	Elapsed Time: 46 sec	Elapsed Time: 161 sec
Orbit Prediction (OP)	Elapsed Time: 16 sec	Elapsed Time: 61 sec
Event Prediction (EP)	Elapsed Time: 8 sec	Elapsed Time: 92 sec

3. Test of the Flight Dynamics Automation

Following the analysis and design of FDA in Lee et al. (2009), FDA is implemented by using C# programming language based .Net Framework 2.0 environment. The experimental result is performed on HP workstation (Intel Xeon CPU 5160 @ 3.0 GHz, 2.99 GHz, 4 GB RAM) with Windows Server 2003 operating system. The experimental test consists of three parts, such as the performance, the reliability and the stability. The performance test is based on the static analysis and the required time of the FDS by comparing the manual operation with the autonomous operations of FDA. The reliability test is based on the consistency of the autonomous job by comparing the result with the reference data. The stability test is based on the running during the specified time continuously. COMS have the capability for operating its own on-station mission during 48 hours without any ground station contacts. The FDA test period is derived from self-control duration of COMS.

3.1 Performance Test

The static analysis of FDA performance is based on comparing the required steps for the flight dynamics operation. The Figure 4 compares the required operation steps between the manual handling and the job controlling of FDA in case of OD. As shown in the Figure 4, the autonomous job has the advantage for minimizing the manual steps. The number of required step for manual job is 9 steps while FDA is none except the initial job setting. The other tasks such as event prediction (EP), Fuel Accounting (FA), and Orbit Prediction (OP) have the similar pattern presented in Figure 4.

Table 2. Reliability Test Results.

Day+0	OD	OP	EP
Reference	Convergence Criteria: Range RMS <= 10 m Azimuth/Elevation RMS <= 0.01 deg	2010-01-08 00:00:00 x: –23854.233 km y: –34774.418 km z: 11.779 km vx: 2.535101 km/sec vy: –1.739266 km/sec vz: –0.000632 km/sec	Box Center Latitude: 0.0003213 deg Longitude: 128.1492733 deg Altitude: 35788.0789411 deg
Automation Result	2010-01-01 00:00:00 Iteration Count: 10 Range RMS: 9.918183 m Azimuth RMS: 0.010281 deg Elevation RMS: 0.010222 deg vy: -1.739266 km/sec vz: -0.000632 km/sec	2010-01-08 00:00:00 x: -23854.233 km y: -34774.418 km z: 11.779 km vx: 2.535101 km/sec	Box Center Latitude: 0.0003216 deg Longitude: 128.1492726 deg Altitude: 35788.0791344 deg
Analysis result	Converged into the criteria specified in reference result	No difference	10^{-4} degree difference in altitude center value
Day+1	OD	OP	EP
Reference	Convergence Criteria: Range RMS <= 10 m Azimuth/Elevation RMS <= 0.01 deg	2010-01-09 00:00:00 x: –23266.360 km y: –35170.612 km z: 11.909 km vx: 2.564006 km/sec vy: –1.696381 km/sec vz: –0.000900 km/sec	Box Center Latitude: 0.0005339 deg Longitude: 128.1333990 deg Altitude: 35787.9594469 deg
Automation Result	2010-01-02 00:00:00 Iteration Count: 7 Range RMS: 9.040179 m Azimuth RMS: 0.011121 deg Elevation RMS: 0.011001 deg	2010-01-09 00:00:00 x: –23266.360 km y: –35170.612 km z: 11.909 km vx: 2.564006 km/sec vy: –1.696381 km/sec vz: –0.000900 km/sec	Box Center Latitude: 0.0005338 deg Longitude: 128.1333986 deg Altitude: 35787.9594184 deg
Analysis Result	Converged into the criteria specified in reference result	No difference	10^{-5} degree difference in altitude center value

Table 1 compares the elapsed time between manual operation and the autonomous operations. The manual job is performed by the skilled engineer. The measured time is averaged time of several operations. This shows the efficiency of the FDA.

3.2 Reliability Test

In this section, meaning of reliability is simply applied for providing the acceptable result to other systems. The reliability of FDA is tested by checking the result with the reference data which are manually generated with COMS FDS. Two test data sets are prepared according to the each operation such as OD, OP, and EP. The reliability test success criteria are defined in the certain tolerable range respectively. Table 2 shows the result of FDA reliability test.

The data used in orbit determination contains noise for 10 m (1 σ) range measurement, and 0.011 deg (1 σ) azimuth and elevation measurement. Orbit determination result shows that the RMS is maintained 10 m convergence criteria. Moreover, the number of iteration count for orbit state convergence is reduced from 10 to 7 on day 2. Orbit prediction result shows if the same epoch orbit elements are applied, then the propagated result is same with reference data. At last, the orbit box

Table 3. Stability Validation Test Results.

Time	Task	Automation Result
Day+0 (2009-8-13) KST 09:00:00	FA	Result: Success Complete Time: 09:00:01 (1 sec elapsed)
Day+0 KST 10:00:00	OD	Result: Success Complete Time: 10:00:53 (53 sec elapsed)
Day+0 KST 11:00:00	OP	Result: Success Complete Time: 11:00:16 (16 sec elapsed)
Day+0 KST 12:00:00	EP	Result: Success Complete Time: 12:00:08 (8 sec elapsed)
Day+1 (2009-8-14) KST 09:00:00	FA	Result: Success Complete Time: 09:00:00 (less 0 sec elapsed)
Day+1 KST 10:00:00	OD	Result: Success Complete Time: 10:00:39 (39 sec elapsed)
Day+1 KST 11:00:00	OP	Result: Success Complete Time: 11:00:16 (16 sec elapsed)
Day+1 KST 12:00:00	EP	Result: Success Complete Time: 12:00:08 (8 sec elapsed)
Day+2 (2009-8-15) KST 09:00:00	FA	Result: Warning message display because of telemetry data is not arrived Complete Time: 09:00:00 (less 0 sec elapsed)
Day+2 KST 10:00:00	OD	Result: Error message display and alarming operator because of mis-formatting measurement data receiving Complete Time: 09:00:00 (less 0 sec elapsed)

statistics difference is about 10^{-4} degree with the reference data. This difference is caused by the precision of input values in the archived data format. However, this precision difference is negligible because the difference is in tolerable range for mission operation.

3.3 Stability Test

Stability test of FDA is performed by continuous running for 49 hours. The test data set consists of 48 tracking and ranging data (one file per hour), 2 telemetry data (one file per day) for 24 hours and an additional erroneous tracking and ranging data at 49 hours. The test data set guarantee the normal operation for 2 days at least. The error data is prepared to test the FDA's error handling capacity. The period of test execution is started at 09:00:00 13/08/2009. Fuel accounting execution time is set at AM 9:00 in every day, orbit determination execution at AM 10:00 in every day, orbit prediction execution time at AM 11:00 in every day, and event prediction execution time at AM 12:00 in every day. Table 3 shows the result of FDA operations. The FDA has the operational stability to provide continuous running required for the autonomous operations.

4. Conclusions

Implementation and test of Flight Dynamics Automation (FDA) have been described with regard to its usability. The FDA test is performed by linking with COMS Flight Dynamics System (FDS). FDA controls FDS to perform automatic job processing at the pre-defined time or activated by the external event. The experimental test result shows its performance, reliability and stability. The developed FDA decrease the operator's manual jobs and prevents the manual mistakes properly. However, in satellite mission control system, no matter how high the automation system development level, it's hardly satisfy the merits of system operation by full-skilled operator with long-term experience. The purpose of FDA is not to replace the whole manual steps but to support the operator to increase the maintainability of FDS. Moreover, it's not difficult to estimate the benefit of time and cost caused by satellite operation systems quantitative growth.

For the future work, the systematic handling of the exceptions is required to increase the reliability. In order to increase the stability to support geostationary satellite mission, more experiments also required along with real operation system. In addition, thoughtful operation scenario will be increase the utilization of the automation flight dynamics system.

Acknowledgements: This work was jointly carried out under the project of Korea & Spain Innovating (KSI). The work by the Electronics and Telecommunications Research Institute (ETRI) and Satrec Initiative was carried out under the contract with the Korea Ministry of Knowledge Economy (MKE) for 'Development of Core Technology for Automatic Satellite Control System'. The work by the GMV Aerospace and Defense was carried out under the contract with the Spain Center for the Development of Industrial Technology (CDTI).

References

Lee, B.-S., Hwang, Y., & Kim, H.-Y. 2008a, Automation of the Flight Dynamics Operations for Low Earth Orbit Satellite Mission Control, Proceedings of International Conference on Control, Automation and Systems 2008, pp.2222-2225

Lee, B.-S., Hwang, Y., Park, S., & Lee, Y.-R. 2009, JA&SS, 26, 267

Lee, B.-S., Kim, H.-Y., Hwang, Y., & Kim, J. 2008b, Flight Dynamics Operations for COMS Satellite Mission Control, Proceedings of 26th International Communications Satellite Systems Conference (ICSSC), AIAA2008-5500