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AUTOMATED FLIGHT DYNAMICS SYSTEM FOR THAICHOTE SATELLITE

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In this paper, we present the development of the flight dynamics system used for the operations of the Thaichote satellite. The system comprises the orbit detemination, orbit propagation, event prediction and orbit control maneouvre modules. The ground-based orbit determination employs the spacecraft's navigation data retrieved from the onboard GPS receiver on a daily basis. Using the estimated orbital state vector from the orbit determination module, the equations of motion are integrated forward in time to predict the satellite states. The higher geopotential harmonics as well as other disturbing forces are taken into account to resemble the environment in low-earth orbit where the satellite is operating. Using a highly accurate numerical integrator based on the Burlish-Stoer algorithm, the satellite's ephemeris can be generated accurately even for long-term predictions. Events occurring during the prediction course that relates the mission operations are detected and reported. They include the drift of groundtrack and local solar time of the orbital nodes, which are vital for orbit control maneouvre planning. We also propose the automation system to handle all the flight dynamics routines, where the spacecraft operations require only initial parameter setup via the user-friendly graphical user interface.

INTRODUCTION

Thaichote is Thailand's first commercial Earth-Observation Satellite (THEOS) [1]. It was launched into a Low-Earth Orbit (LEO) in October, 2008. In order to serve its main payload, a high-resolution multi-spectral Earth imaging system, the satellite was inserted into a Sun-Synchronous Orbit with the Local Solar Time (LST) of the descending node at 10 A.M. A repeat-groundtrack condition of 26 days, 369 orbits has been assigned for exact revisit to the areas of interest on the ground. A frozen orbit is also preferable for altitude variation minimization. The mission's specialist orbit conditions are evaluated by incorporating the perturbation effects, especially from the nonspherical Earth [2]. The required orbital configuration for the Thaichote satellite is summarized in Table 1.

The Flight Dynamics System (FDS) takes the responsibility for keeping the satellite's orbit at such requirements throughout its operational life-time. It also propagates the satellite orbital states forwards in time and generates the ephemeris data required for the mission planning and

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operations. The FDS routines comprise the Orbit Determination (OD), Orbit Prediction (OP), Event Prediction (EP), Orbit Control Maneouvre (OC) and Propellant Accounting (PA).

In this paper, we describe an in-house development of the Thaichote's FDS, called EMERALD project. We also propose an Automatic Flight Dynamics System (AFD), where only initial parameters setup through the graphical user interface is required, and the FDS routines can be executed without any intervention from the operator.

Table 1. Thaichote Mission Orbital Configuration.

Orbital Parameters	Value
Altitude	822 km
Inclination	98.76 deg.
Frozen eccentricity	0.001146
Mean Motion	14+5/26 rev./day
LST of Descending Node	10.00 A.M. +/- 2 min.

THE FLIGHT DYNAMICS SYSTEM

The Thaichote's FDS is a computer-based software system with the structure shown in Figure 1. It is operated by the system management and database management, and supported by graphical user interface for user-friendly operations. The onboard GPS system serves the FDS with the satellite navigation. The ephemeris data generated from the FDS will be distributed for various satellite operations, namely the telemetry and telecommand, transponder activation, antenna pointing and payload operation planning. Each module inside the FDS has its own input and output format, and a dedicated GUI for routine setup and results display.

Obit Determination Module

The OD module retrieves navigation data from the on-board GPS receiver on a daily basis. The satellite orbital states, i.e. position and velocity vectors, are estimated using the differential correction algorithm [3], where the residuals between the observed and the estimated states are minimized using a Weighted Least-Squares cost function. Some solved-for parameter, such as drag coefficient, is also included in the estimated state vector for the evaluation of the orbital decay rate. The required initial setups are the initial state vector obtained from propagated states from the previous day, and the period for GPS observation data to be retrieved. Figure 2 shows the OD module's GUI. The determined orbital states, as well as the covariance matrix and estimated residuals, are stored in the database. Figure 3 shows a typical residual profile of the estimated position vectors at each observation epoch.

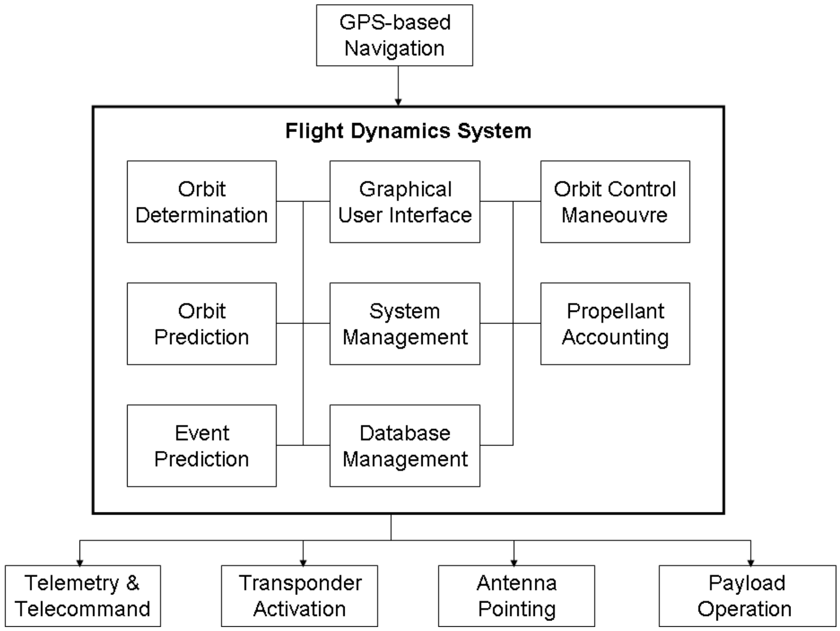

Figure 1. The Thaichote Flight Dynamics System.

Figure 2. GUI of the Orbit Determination Module.

Figure 3. Typical Position Residuals from Orbit Determination.

Orbit Propagation Module

The accuracy of the OP depends on the numerical integration method, as well as the mathematical modeling of the perturbation forces. For Thaichote, the Bulirch-Stoer algorithm [4] has been applied in the integration process of the orbital dynamics. The incorporated Richardson extrapolative method is considered to be the fastest and most accurate, and it is particularly suitable for our near-circular orbit where the dynamics topology is quite uniform throughout the integration course.

For the Earth's gravitational force modeling, it is optional between WGS84, GEM10B, and JGM-2 models to be used in the Thichote's FDS. Although degree and order of the gravitational harmonics can be included up to a higher number, a truncated version with 36×36 terms has been proven to be sufficient for our mission operations.

The gravitational attraction from the Sun and the Moon are modeled as point-mass third-body objects. The third-body object's position vector with respect to an Earth equatorial plane coordinate system is important not only for the acceleration calculation, but also for the prediction of the eclipses. The Jet Propulsion Laboratory Development Ephemeris model [6] has been adopted for precise Solar and Lunar ephemeris.

Some non-conservative forces, though very small compared to their conservative counterparts, can cause secular variations in some orbital elements, especially the decaying of the altitude caused by atmospheric drag. It directly affects the satellite's groundtrack and causes a timeparabolic function drift. The Jacchia-Roberts model [7] has been adopted for the modeling of such an effect. It computes the atmosphere density from data on solar activity index, $F_{10.7}$, and from the geomagnetic index, K_p.

The solar activity also affects the solar radiation pressure acting on the spacecraft surface. A cylindrical cone of the Earth's shadow is assumed in the evaluation of the perturbing force. Orbital perturbations resulting from shadow transits are treated by the introduction of shadow function that measures the degree of the Sun's occultation by a body like the Earth or the Moon.

To execute the OP, the determined states from the OD module are required as the initial conditions for the dynamics integration process. The integration duration, as well as the time step for displaying the results can be assigned through the GUI as shown in Figure 4. The OP module outputs are ephemeris data files in various coordinate systems.

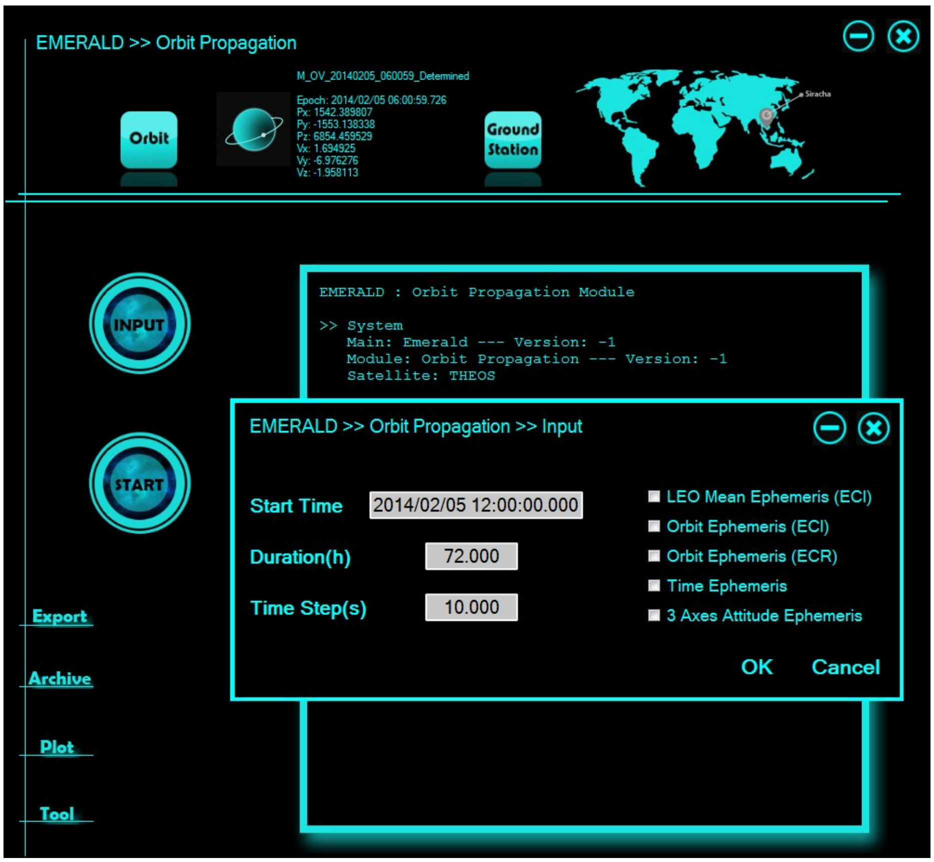

Figure 4. GUI for Orbit Propagation Module.

Event Prediction Module

Events that are relating to satellite operations are detected in the EP module, both on a day-by-day and event-by-event basis. Some relevant parameters are also calculated. They include the equator crossing position and time, satellite rise/set time and its position in the topocentric coordinates, which is useful for transponder activation and antenna pointing routines. The prediction of eclipses both from the Earth and the Moon, as well as satellite sensor intrusion time will help in payload planning and electrical power management.

Some stationkeeping-related parameters generally require long-term prediction. They include groundtrack error, local solar time of the orbital nodes and the biased eccentricity vector from the mission's frozen condition, which can be found by converting from the osculating to mean orbital elements. Figure 5 shows a long-term prediction of the groundtrack error with the control band of ± 40 km marked. Short-term simulation may be also required for verification due to the uncertainty of the atmospheric drag model. The drift in local solar time shown in Figure 6 is caused mainly by the change in orbital inclination, perturbed by the Sun's attraction. The local solar time control window has been set within ± 2 minutes.

Orbit Control Maneouvre and Propellant Accounting Modules

The OC module takes responsibility on planning delta-V strategies for keeping the satellite's groundtrack and the nodes LST inside the predefined windows. It calculates for the optimized delta-V vector and execution time, as well as conducts the thruster calibration.

The PA module analyses the remaining fuel mass inside the spacecraft's fuel tank. Two methodologies are adopted in our FDS, namely the Pressure-Volume-Temperature method that uses the temperature and pressure telemetry data for the calculation, and the Thruster-On-Time method that uses the pulse information from thruster firing.

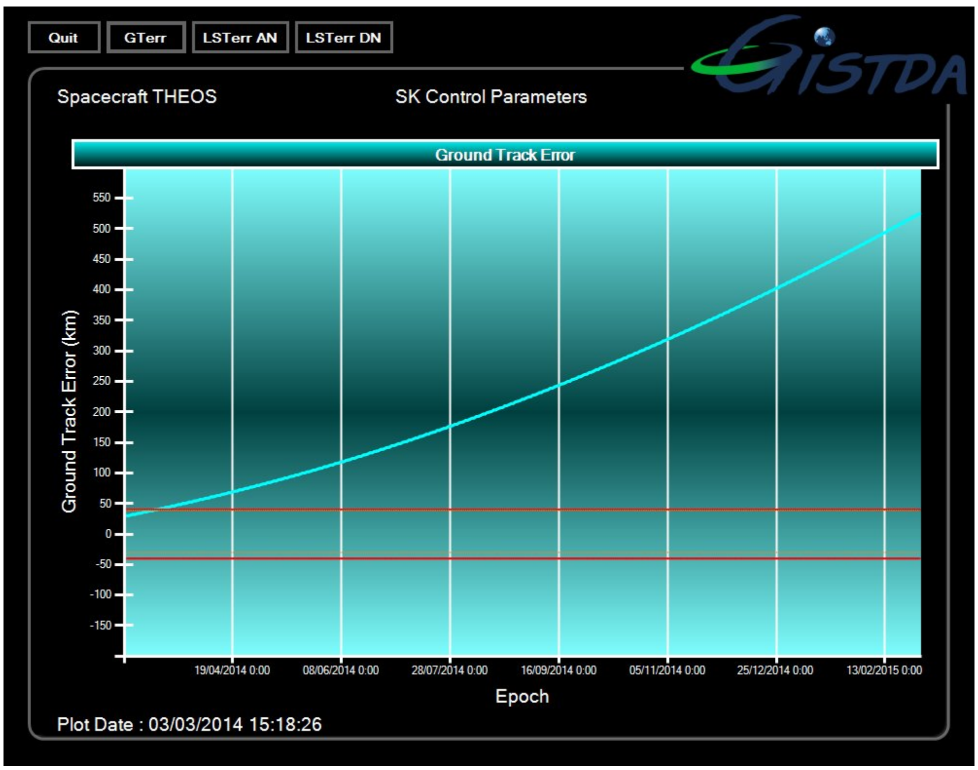

Figure 5. Plot of Groundtrack Error.

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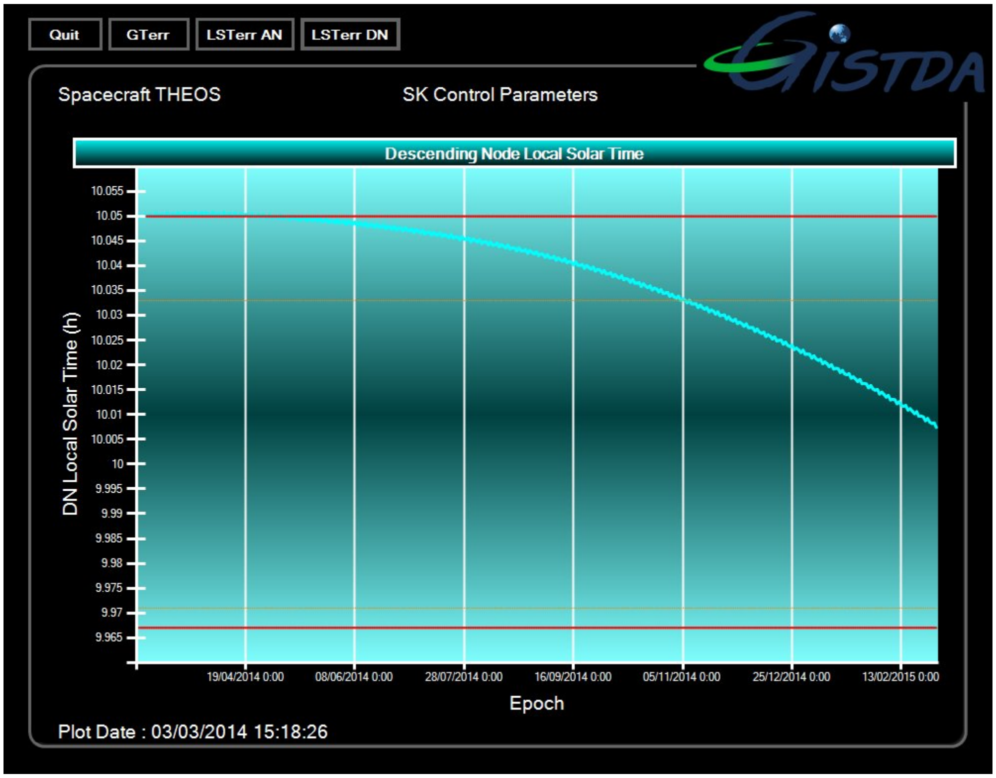

Figure 6. Plot of Nodal Local Solar Time Drift.

AUTOMATED FLIGHT DYNAMIC OPERATIONS

In order to save the man-hour resource in the satellite mission control and to prevent the satellite operator from mistakes, an automation FDS is proposed for handling the daily routine operations. As depicted in Figure 7, the Flight Dynamics Automation is a high-level driver for the FDS. It sends commands to execute the programs inside the FDS. The Service Executor makes decisions based on the time-checking and event-checking routines. The automatic operation of each module can be divided into sequences as follows.

Automation of Orbit Determination

The OD requires a priori orbit states from the stack data file for starting the weighted least squares orbit estimation. Automation of OD focuses on the input and output file handling and execution of the OD program. Its task sequences are as follows.

S1: At a predefined time, check if there is a new GPS data file in the designated directory.

S2: Generate a new input data file for orbit determination program.

S3: Execute orbit determination program.

S4: Evaluate the orbit determination results.

S5: Generate a report file.

S6: Update orbit stack data.

S7: Move the old track data file to the specified directory according to the OD execution result.

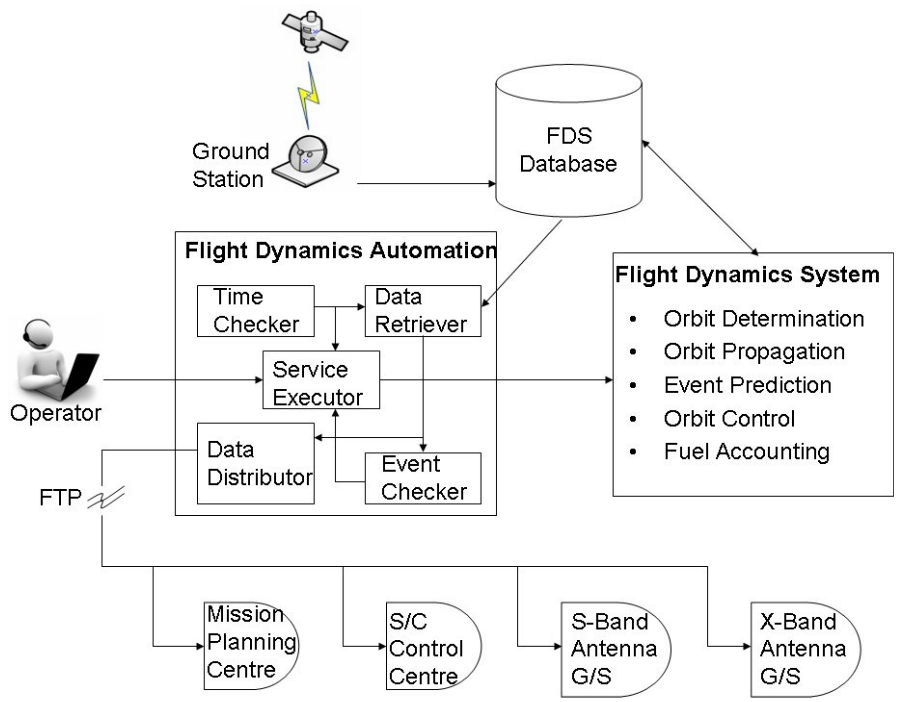

Figure 7. The Flight Dynamics Automation System.

Automation of Orbit Propagation

The orbital states obtained from OD are used as initial conditions. The OP is performed using the numerical integration of the dynamics equations. Automation scenario of OP is as follows.

S1: At a predefined time, check if there is new orbit stack data in a designated directory.

S2: Generate a new input data file for orbit prediction program.

S3: Execute orbit prediction program.

S4: Evaluate the orbit prediction results

S5: Generate a report file for orbit prediction.

Automation of Event Prediction

Once enabled, the detection of events will be run parallel to and with the same sequence as the OP module. It outputs event files both on a day-by-day and event-by-event basis. The satellite visibility prediction file includes the ephemeris data in topocentric coordinates used for the antenna pointing control system. It requires a relatively small step size (100 ms in our case), and it is produced separately from other output files.

Automation Propellant Accounting

In the evaluation of the remaining propellant, both the Pressure-Volume-Temperature and the Thruster-On-Time calculation methods will be executed. The sequence of PA automation is as follows.

S1: At a predefined time, check if there is new telemetry data in a designated directory.

S2: Generate a new input data file for propellant accounting program.

S3: Execute propellant accounting program.

S4: Evaluate the propellant accounting results.

S5: Generate a report file for propellant accounting.

S6: Update the spacecraft database.

The main GUI of the Flight Dynamics Automation is shown in Figure 8. It is simply enabling buttons for the FDS modules, where the operation status is continuously shown while the system is processing. Once enabled the FDS routines can be executed and the output data can be sent to its related subsystems, as well as stored in the system database autonomously without any intervention from the operator, except when some fault is detected and alarmed.

CONCLUSION

We have presented the development of the automatic flight dynamics operations for the Thaichote satellite. The automated flight dynamics system is proposed to replace the traditional operation, where a number of dedicated personnel are required for handling the tasks. Via the user-friendly graphical user interface, the spacecraft operations will require only initial parameter setup. The proposed system can perform algorithm executions, flight dynamics data archiving, file formatting and file distribution to different subsystems without any intervention from operators. The man-hour resource, human error and overall operational cost are expected to be reduced from this automation system.

Figure 8. Main GUI of The Flight Dynamics Automation.

ACKNOWLEDGMENTS

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