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Automated Command Executive for Real-Time Mission Operation Management

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Abstract

The ACE (Auto Command Execution) module is a critical software component designed for space operations, focusing on automating and optimizing the command generation, uplink scheduling, and real-time telemetry analysis for spacecraft. This module is integral in managing daily command plans by generating commands based on predefined rules set in the Operation planner and satellite configuration files. It ensures the efficient execution of space missions by scheduling uplink commands in different operational modes and adapting to real-time operational challenges. In relation to this, the Feedback Updating Routine which is a subsystem in the ACE module, processes feedback from real-time Auto-Commanding software enabling the command status to remain relevant as new information is acquired. This routine guarantees that the status of area which has to be uplinked is always incorporated in the feedback files and these files, on their part, are made use of by the Auto Command Scheduling component to develop corresponding uplink schedules. In addition to that, the ACE module is also capable of dealing with incoming streams of telemetry data and determining and correcting for undesirable spacecraft behaviour throughout the course of the operations. This capability enables quick adaptations and decision making to be made, thus minimizing the risk and enhancing the safety of the mission. The research presented delves into the Layout Application and operational efficacy of the ACE module highlighting its importance in space mission operations. The read too explores the module operation in real-time scenarios showcasing its hardiness in managing the complicated ties of satellite operations

Keywords: ACE

Acronyms/Abbreviations

ACE – Automated Command Executive

1. Introduction

1.1 Background

Space missions have become increasingly complex, requiring advanced automation techniques to manage operations effectively [1]. Traditional command execution methods depend heavily on human intervention, which introduces potential delays and errors. The growing complexity of modern spacecraft necessitates intelligent automation systems that can handle command generation [2], uplink scheduling, and telemetry monitoring with minimal operator input.

The ACE module is an innovative solution designed to enhance spacecraft autonomy and mission reliability. By integrating automated command scheduling, dynamic feedback processing, and telemetry-driven decision-making [3,4,5,6], it significantly reduces operational risks. The ACE module enables real-time adaptation to mission conditions, ensuring that spacecraft commands remain optimal and updated as new data is received.

1.2 Objective

The objectives of the ACE system can be summarized as follows:

1.2.1 Automate Command Generation and Scheduling

To replace the manual generation of commands with automated, predefined schedule based on operational parameters.

1.2.2 Feedback Integration

To incorporate real-time feedback from spacecraft telemetry and adapt the command sequence as needed.

1.2.3 Improve Mission Reliability and Efficiency:

To ensure that the satellite receives the correct commands at the right time, improving operational efficiency and reducing human intervention.

2. Material and methods

2.1 ACE Module System Architecture

The ACE module architecture consists of several interconnected subsystems as shown in Fig. 1 that work together to automate command execution and telemetry processing. The primary components include:

2.1.1 Command Generation Module

The Command Generation module integrates the schedule set in operational planners and the command configurations allowed for the satellite. The operational planner contains the set of predefined mission rules and the guidelines defined for the satellite operations. Based on the operational planner, the module generates the sequence of commands and validates them. Once validated, the command sequence is compared to status of previous uplinks through the feedback updation routine and is updated based on it. The updated sequence is ready for uplink scheduling by the next module.

2.1.2 Feedback Updation Routine

The feedback updation routine monitors the command uplink status based on logs and telemetry. It compares the previous sequence of uplink from logs to telemetry and validates their execution on the spacecraft. Based on the telemetry, the routine provides feedback to command generation module for ensuring the sequences are up-to-date. This prevents uplink of out-dated or redundant commands

2.1.3 Auto Command Scheduling Component

The module optimizes the scheduling of uplink for command sequence based on satellite visibility, timing constraints and operational priorities. It generates the uplink timeline for the command sequence meeting all the real-time mission constraints. Finally, it produces the optimal command uplink timeline that meets all the requirements and are ready for uplink to the satellite.

2.1.4 Telemetry Health Processing Module

The satellite telemetry has to be regularly checked for anomalous behaviours such as hardware malfunctions or system deviations. These deviations can be exacerbated by the existing command sequence which is scheduled for uplink and hence the command sequence needs to be updated and regenerated accordingly. The input for telemetry health processing module triggers for the regeneration of new command sequence by the command generation module.

2.1.5 Master Module

The module functions as the over watch during final uplink process in real-time triggering the command generation module for regenerate in case of negative status from telemetry health processing module or breaks in command sequence uplink. It is time synchronized module which triggers all the required modules and interfaces the final outcome to achieve the complete uplink of command sequence to the satellite.

2.2 ACE Module Workflow

The workflow shown in Fig. 2 enables real-time command adaptation, ensuring efficient decision-making based on dynamic mission parameters. It can be divided into multiple phases based on the visibility of the satellite

2.2.1 Pre Visibility Phase

It starts with Master module running as the trigger and interrupt module which over watches the timely execution of the required module based on the visibility schedule of the satellite. It triggers for the feedback routine before the visibility of the satellite to retrieve proper status of the uplink carried out over the previous visibility of the satellite. This status is passed on to the command generation module along with required configuration files and operation plan for generating the command sequence. The validated command sequence is then passed on to the command scheduling module which prepares the timeline for the command sequence uplink.

2.2.2 Visibility Phase

During the visibility phase, the master module checks for negative status form the telemetry health processing module and triggers for regeneration if required. In nominal case, the uplink schedule planned before the visibility is carried out. The master module also continuously checks for the proper execution of the all the required modules. In case of uplink breaks it triggers for regeneration and follows the sequence similar to before visibility phase.

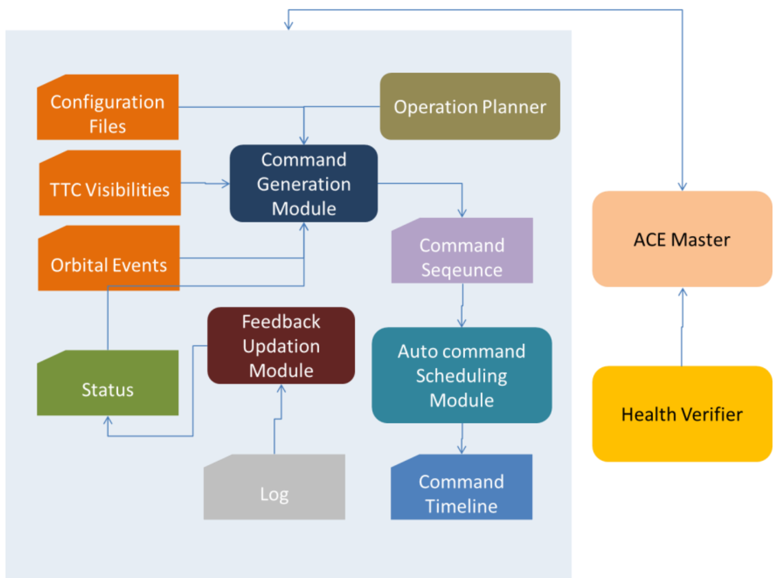

Fig. 1. Full S/W Architecture

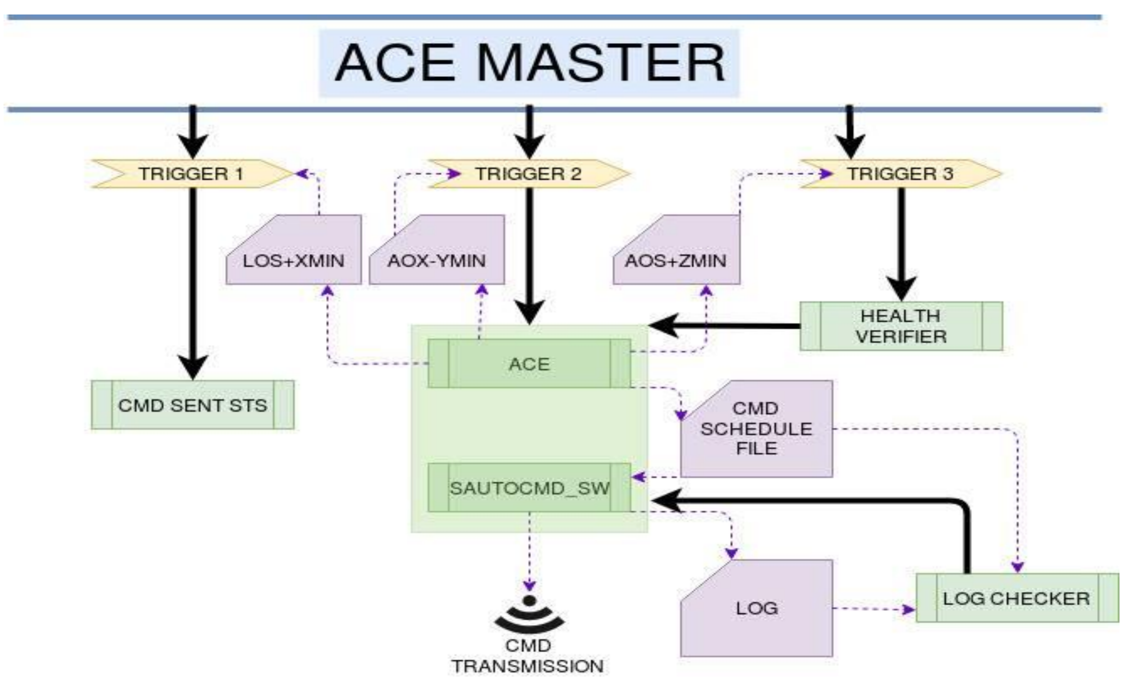

Fig. 2. ACE workflow

3. Results

This section demonstrates how well Auto Command Execution module performed for spacecraft operations. There are several cutting-edge approaches implemented to handle the intricate telemetry data.

- The primary objective is to provide full automation of commanding, from generation to uplink without human intervention.
- Checking continuation of commanding during Real-time pass
- Re-initiating the full process in case of any failure

3.1 Command Generator

The command generation module is responsible for generation of the command sequence. As shown in Fig. 3 the GUI provides the user to view the scheduled operations, time line planned for full day, and they can view and verify the commands scheduled in the operation. It also provides user the latest operation schedule in upcoming visibilities. It also provides the information about the operation which has already completed. It alerts the user, if any error has observed during scheduling or during up linking of commands.

3.2 Auto Command Scheduling

This module is responsible for scheduling the operation as per user defined. As shown in Fig. 4, the GUI provides the user to schedule operation with these features

- Operation can be defined along with execution rule.
- Once operation is defined user can enable or disable the operation.
- Provides option to change in TTC schedule (while running ACE).
- Any special operation related command file can be scheduled for up-linking

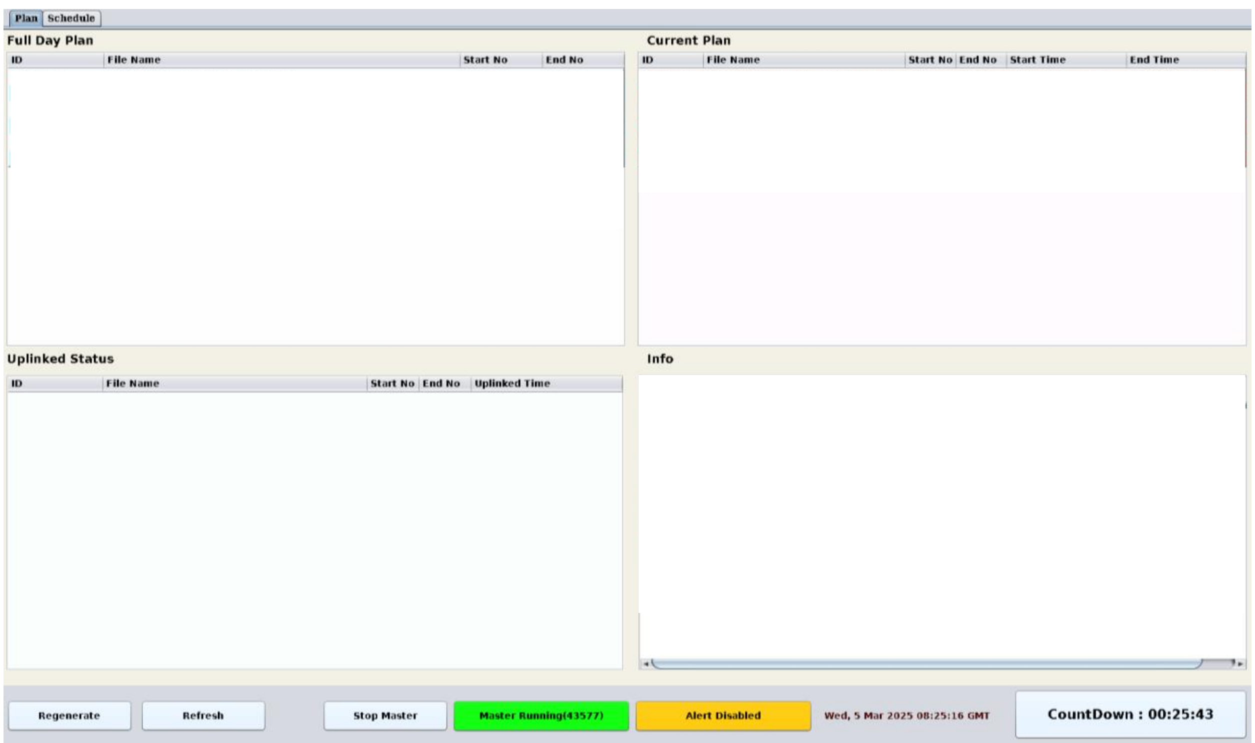

Figure 3 ACE Status GUI

3.3 Feedback Updation Routine

This module is responsible for status generation on the command sequence uplinked to the satellite. As shown in Fig. 3, the status of the uplink can be monitored from the GUI. The module ensures there is no out dated or redundant commands are uplinked to the satellite

3.4 Telemetry Health Processing Module

This module provides status of GO or NO-GO for command sequence uplink to the satellite. The master module receives the status for uplink clearance from the health verifier module as per the above discussed workflow. The status can be seen in the GUI in Fig. 3 through the information tab available.

3.5 Master Module

This module is responsible for the overall working of all the required modules. The status of it can be monitored through the GUI in Fig. 3 which is colour coded for easy user access. The user can also disable and take manual control through the GUI.

4. Discussion

The ACE module's effectiveness in automating command execution and telemetry processing highlights the potential of intelligent software-driven spacecraft management. Its ability to adapt to real-time data and generate error-free command schedules marks a significant advancement in mission automation technologies.

However, several challenges were observed during the implementation phase. Latency in real-time telemetry processing was a notable issue, which was mitigated through data buffering optimization. Additionally, ensuring high accuracy in feedback incorporation required the implementation of redundancy checks and data validation routines.

Future improvements could integrate machine learning algorithms for predictive anomaly detection, allowing the ACE module to proactively anticipate spacecraft malfunctions. Furthermore, cloud-based data processing architectures could enhance scalability, making the system more adaptable to multi-satellite operations.

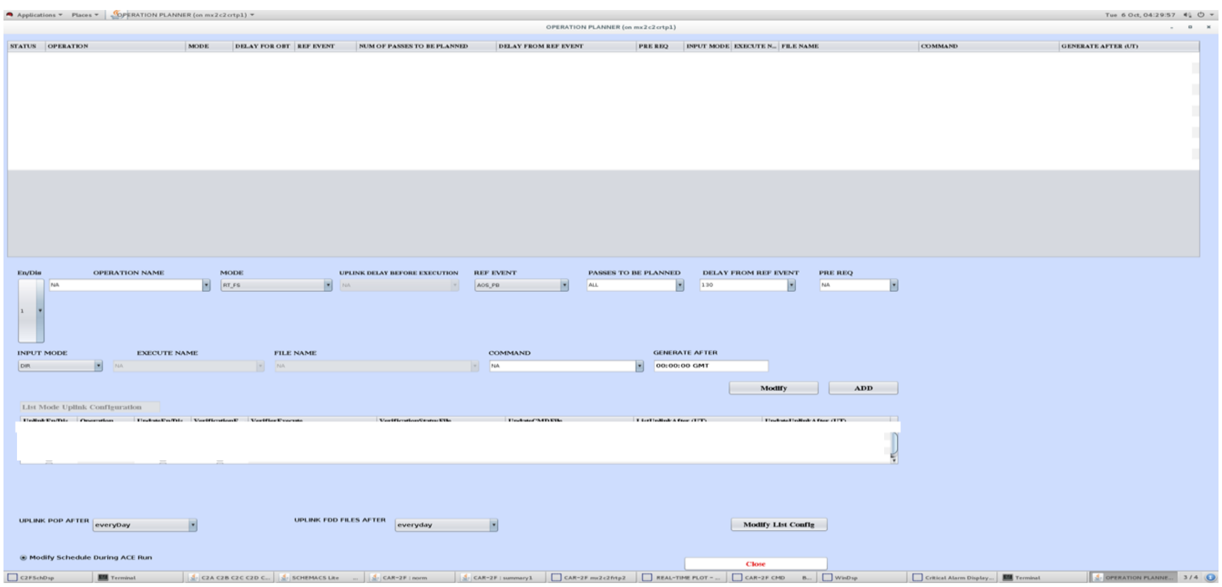

Fig. 4. ACE Operation Planner

5. Conclusion

The ACE module represents ground breaking advancement in automated command execution for space missions. By integrating automated scheduling, real-time feedback updating, and telemetry-driven decision-making, it significantly enhances mission efficiency, accuracy, and adaptability. The research findings confirm that automation-driven solutions play a critical role in modernizing space operations, reducing manual errors, and ensuring mission success.

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