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Title

A finite state machine approach to nano-satellite SW design: the HERMES case study

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Abstract

The Space community interest in small-size spacecraft increased considerably in recent years, being the number of launched nano-satellites and CubeSats grown with an exponential trend in the last decade. A fundamental aspect for the success of such missions consists into the design of reliable on-board software, which is a vital element of the platform and in charge of performing Fault Detection Isolation and Recovery (FDIR) functions [1]. The problem of nano-satellites' software design is not new and, in literature, different approaches can be found, often relying on a Finite State Machine (FSM) to execute the mission functionalities in a deterministic manner [2,3,4]. However, there is still the lack of a consolidated and broadly recognized framework for designing the logics underlying the on-board software's FSM. With the purpose of making some steps forward in this direction, a multi-disciplinary and systematic approach to break down the software design process into effective steps is proposed and described in the paper.

First, starting from missions' typical high-level functionalities, some FSM modes, as LEOP, nominal routine (NOM) and hard safe mode (HSAFE), are identified and the connecting transitions among them are defined. Then, the logic underlying each mode is described accounting for either the relevant requirements to be satisfied, the mission's operations and the actual functioning of the spacecraft's components. Secondly, in order to check the compatibility with the spacecraft's design and operations, the logic's design is supported and consolidated with analyses involving the spacecraft subsystems, such as the attitude determination and control (ADCS), the power generation and management, and the on-board data handling. During such process, particular attention is paid to the design of the nano-satellite's FDIR and to its translation into the FSM logic, which shall be achieved by means of monitoring functions that perform the Fault Detection (FD) and the soft safe (SSAFE) routines, which are devoted to the Fault Identification (FI) and, possibly, fault correction. Afterwards, the derived FSM logic is represented in detail with the Specification and Description Language (SDL), which allows the formal verification of the FSM and bridges the high-level definition to the final on-board software implementation. This level of the FSM definition process is developed in an Opengeode environment, an open-source graphical editor developed by the European Space Agency (ESA) inside the TASTE tool. In such a way it is possible to directly identify possible faults in the prototyped logics, relying on a more accurate and with wider coverage FSM verification.

The described approach will be then applied to the High Energy Rapid Modular Ensemble of Satellites (HERMES) mission, funded by ASI and EC, as a case study [5, 6]. HERMES' space segment is composed by a LEO constellation of six nano-satellites, with the objective of detection, localization and communication to ground of energetic astrophysical transients. To achieve such complex objectives, the on-board software is executed by two different OBCs on the spacecraft (i.e., OBC-MAIN and OBC-ADCS), while interfacing with other spacecraft's components, as the payload, the power module, the telecommunication modules, the sensors and the actuators. Each software part (i.e., SW-MAIN and SW-ADCS) is structured according to its own FSM and the two are interfaced by means of structured data commands and monitoring parameters, with a "master-slave" logical architecture. The HERMES mission's FDIR strategy is also presented in this paper. Such strategy has been designed to grant the safety and reliability of the system, minimising the on-board recovery actions and leaving most of them to ground intervention, while putting the system into a HSAFE mode that maximises both the attempts to communicate to ground and the power budget margin. Specifically, the manuscript will discuss the monitoring functions that carry out the FD logics of each FSM mode, the FI dedicated routines and the few FR actions that are kept on-board.

In conclusion, the paper will propose an effective approach for nano-satellite's software design and it will apply it to the HERMES mission, up to the formal verification in SDL.

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