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Plug-and-play design approach to smart harness for modular small satellites ☆

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ABSTRACT

A typical satellite involves many different components that vary in bandwidth demand. Sensors that require a very low data rate may reside on a simple two- or three-wire interface such as I^2C, SPI, etc. Complex sensors that require high data rate and bandwidth may reside on an optical interface. The AraMiS architecture is an enhanced capability architecture with different satellite configurations. Although keeping the low-cost and COTS approach of CubeSats, it extends the modularity concept as it also targets different satellite shapes and sizes. But modularity moves beyond the mechanical structure: the tiles also have thermo-mechanical, harness and signal-processing functionalities. Further modularizing the system, every tile can also host a variable number of small sensors, actuators or payloads, connected using a plug-and-play approach. Every subsystem is housed in a small daughter board and is supplied, by the main tile, with power and data distribution functions, power and data harness, mechanical support and is attached and interconnected with space-grade spring-loaded connectors. The tile software is also modular and allows a quick adaptation to specific subsystems. The basic software for the CPU is properly hardened to guarantee high level of radiation tolerance at very low cost.

1. Introduction

Embedded harness hosts power and data harness subsystems, which are very vital elements and distribute electrical power and signals all around the spacecraft subsystems and payloads [1]. A smart harness technique embeds power, data and radio frequency harness with additional signal-processing capabilities. This paper proposes an innovative approach to smart harness in the design of modular small satellites. Modular or module-based design approach is based on dividing a system into smaller parts or modules that can be created independently and assembled together to achieve the desired performance of the complete system. This design approach is in general low cost because the design, qualification and test cost are shared among multiple modules. The modules are developed in parallel rather than a typical system developed using serial approach and this results in the reduction of design time. Modular design combines the advantages of standardization with those of customization [2–6]. Upon fabrication, the modules are rapidly combined into a custom-printed circuit board layout and the job of prototype testing can begin. In addition, the modular design significantly reduces the cost of the overall system because the cost is shared among a number of modules that can be reused in the system many times. The AraMiS architecture is based on standardized panel bodies or blocks called *tiles*, which are used to build small satellites according to the specific requirements [7–8]. Each tile offers a power and data standardized interface with mechanical support for small subsystems. The outer tiles are of two types: power management tile and telecommunication tile. The power

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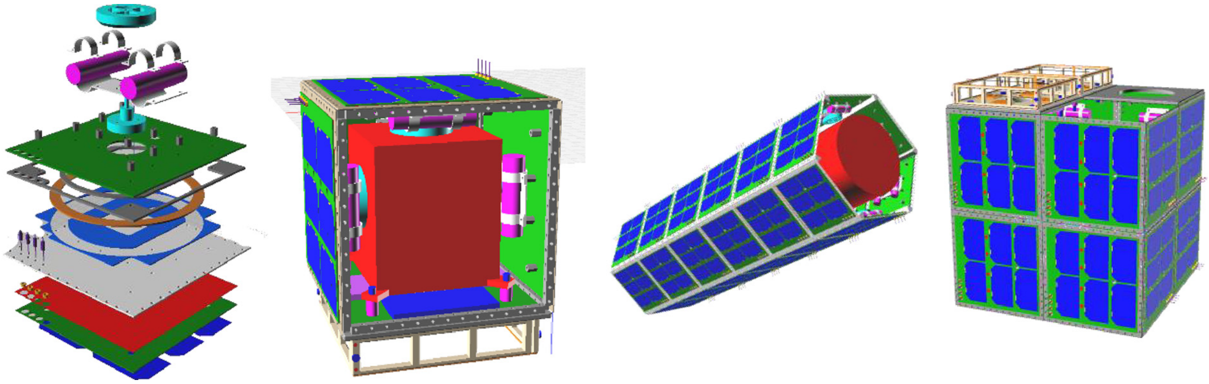

Fig. 1. Drawing of single tile and different spacecraft configurations by arranging tiles in certain configurations.

management tile uses a high level of integration and a compact stack of different materials and resins. It is composed mostly of solar panels, rechargeable batteries, a battery charger and a housekeeping module to keep track of telemetry data inside the tile and an active magnetic and inertial control system. An appropriate number of such tiles is placed around a cubic or any other desired shape and represents a pre-designed and pre-assembled modular architecture. Fig. 1 shows the drawing of a single tile and some possible satellite configurations by arranging a number of tiles.

Telecommunication tiles are composed of microcontroller-based programmable transceiver, 437 MHz and 2.4 GHz modem, power amplifiers (for transmission) and low-noise amplifiers (for reception) and an antenna system. This kind of tile is placed on one of the faces of the satellite, preferably pointing to the ground, and manages the exchange of data and commands to/from ground stations.

The tiles are modular and scalable at mechanical, protocol and hardware/software levels. By modularity at the mechanical level we mean that the tiles and subsystem modules can be fabricated in any desired dimension and combined together in any desired satellite configuration. Scalability at electrical level is obtained using the symmetrical electrical signal scheme for every connected module. Modularity at the protocol level is achieved using a basic protocol consisting of multiple communication protocols, thus giving flexibility for onboard communications.

Every subsystem is either embedded onto the tile or housed in daughter boards, which are attached to the tile via commercial spring loaded connectors. The tiles having pluggable connectors can either be used as a test bed for testing of individual subsystem modules or be used as a motherboard in flat sat configuration. The subsystems support multiple communication protocols using smart mapping mechanism. A one-wire memory for storing configuration and calibration data is associated with each sensor, including the analog ones. Each tile is therefore a system made of pluggable subsystems, which can be tailored to mission-specific needs without the need for re-design. The tile software is also modular and allows a quick adaptation to the specific subsystem. The basic software for the CPU is properly hardened to guarantee a high level of radiation tolerance.

The paper is organized according to the following sequence. Section 2 describes the modularity at the thermo mechanical level for tile and corresponding pluggable modules that are placed on each tile. Section 3 discusses the modularity at the protocol level. Section 4 describes the UML-based hardware\software co-design of AraMiS architecture using a UML approach.

2. Modularity at the mechanical level

2.1. Tile dimensions

Modularity at the mechanical level is achieved by fabricating the tiles with different mechanical sizes and dimensions and assembling them in different mission-dependent configurations. The tiles have been fabricated using different technologies including Aluminum-based, PCB only and honeycomb structures. The structure and technology of each tile have been discussed, which makes it easier for use in specific missions.

2.1.1. Single-size Al structure

A $16.5 \times 16.5\ cm^2$ tile with 1.6 mm-thick monolithic aluminum structure was used for cheaper and smaller structures. Fig. 2 shows the internal and external views of a single tile containing standardized interconnection points for pluggable modules. The mechanical subsystem is made of chromate conversion-coated alodined Al frame, which bears solar cells, batteries, reaction wheel, motor and all the electronic elements. This Aluminum frame, with its high strength to weight ratio, corrosion resistance and radiation protection characteristics, is normally used in most avionic systems including satellite structures [9]. The single-size Al tiles can be used in any satellite configuration for the LEO orbit, ensuring proper temperature and radiation levels for using normal COTS devices.

2.1.2. CubeSat standard structure

An $8.25 \times 9.8\ cm^2$ tile, with all electronic components integrated and compatible with 1U, 2U, 3U…6U CubeSat dimensions is used [10]. This structure is designed in accordance with standard 1U cubic structure of $10 \times 10 \times 10\ cm^3$ dimensions. Each power management tile has electric power supply (EPS) and attitude determination and control