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Flexible platform based micro-satellite design method

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ABSTRACT

This article proposes a flexible platform based satellite design methodology to achieve the aim of "Faster, Better and Cheaper" in a micro-satellite development process. The micro-satellite platform is divided into components-based software modules and hardware modules that comprise reconfigurable module, universal module and custom-built system in the proposed methodology. As a result, the micro-satellite platform possesses the flexible ability of rapid assembly/replacing according to diverse mission requirements. Application of hardware Plug and Play technology enables the universal module to rapidly connect to the satellite platform. Based on the software bus, the components-based software technique enhances the reuse percentage of the on-board software code, and improves the efficiency of the on-board software R&D. The single-axis air-bearing test bed is constructed based on proposed micro-satellite flexible platform design method using RS232 flywheel and RS422 fiber optic gyro (FOG), which illustrates the efficiency of the developed flexible design methodology.

1. Introduction

With the development of modern micro-satellite technology, short-development-cycle, low-cost and high-reliability have become its trend. Conventional method focused only on satellite platform has been unable to adapt its technology development. In particular, the concept of rapid response satellite has been challenging to the traditional satellite design method, which is proposed in response to the major disaster such as earthquake, floods, snow disasters, and so on. Therefore, it is desirable to develop new design concepts and methods to adapt characteristics of micro-satellite development.

In order to achieve the objective of "Faster, Better and Cheaper" in the micro-satellite development process, Plug and Play (PnP) has attracted great attention in aerospace industry. PnP of satellite systems is an important way to achieve space rapid response [10], which also plays a significant role in rapid system reconfiguration, maintenance in orbit and function extension of the rapid response satellite [1].

Air Force Research Laboratory (AFRL) proposed the 'Plug-and-Play Satellite' (PnPSat) program based on the technology of "Space Plug-and-play" [2,4–6]. PnPSat employs modular components from the structural panels to the guidance devices which thus takes full advantage of the self-describing mechanisms.

AeroAstro developed and built a spacecraft architecture named SMARTbus in 2005, which was also based on modular and "Plug-and-Play" design concept [8]. SMARTBus provides a set of mechanical, electrical, and logical standard for modular satellite. A SMART-Bus spacecraft consists of a stack of hexagonal modules, or "slices", each of which performs a particular spacecraft subsystem function.

Lyke [7] proposed "Monarch" satellite concept in 2012, which can build a complex satellite platform quickly and reliably by arranging a number of open modules.

SPA technology is first applied in nanosatellite by McNutt [9], where three conceptual nano-satellites were designed in their lab, each of which has fully plug-and-play functional networks and internal interchangeable components.

In order to satisfy the requirements of the embedded real-time system, such as extensibility, high reliability and upgrade, the *Online Application Research Company* (OAR) developed a real-time embedded system called SAFER, which can be applied to small satellites [11].

The America Ball & Aerospace Technology Corporation developed an Advanced Spacecraft Electronics (ASPEN) flight software architecture [3] to develop software with high adaptation for different spacecrafts and different space missions, which also addresses the problems in real-time system such as race conditions, deadlocks, and synchronization. It has been shown in space missions since this software architecture is easy to maintain and can adapt to other tasks with little or no change.

Goddard Space Flight Center applied an open architecture called Core Flight Executive (CFE) [12] in satellite software, and the application of standardized interfaces and middleware software bus rendered that all the functional components can come together as

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the satellite software effectively. In this software architecture, software bus is used for the processes and nodes communication and it replaces the traditional connection method among components by using multiple interfaces.

Motivated by the above discussion, also considering the requirement of the rapid response satellite and the current situation of hardware components and payloads in China, a micro-satellite flexible platform design method is proposed in this paper. According to different tasks and roles, the micro-satellite platform is divided into changeable parts, and several fixed and universal parts. These two parts are combined to constitute a flexible satellite platform, which meets different payloads and various mission demands. It can achieve optimal matching between the satellite platform and payloads by reconfiguring or adding some new specific functional modules to the satellite platform. In addition, the technology of the hardware Plug and Play and component-based software based on software bus is applied to facilitate the integration of a whole satellite, and to shorten the satellite development cycle and reduce the development cost to a large extent.

This article first proposes the architecture of flexible micro-satellite platform to satisfy the requirement of rapid components replacing and integration. The proposed satellite design methodology employs Plug and Play micro-satellite technology such as interface reconfiguration, standardized information network and automatic device identification. Second, the software bus with Plug and Play feature and its dynamic loading technique are investigated. Finally, the application of the proposed micro-satellite design method to single-axis air-bearing testbed with RS232 flywheel and RS422 FOG is given, which shows the efficiency and advance of the flexible satellite platform design method.

2. The architecture of flexible micro-satellite platform

In order to achieve rapid replacement and integration of components of satellites, a concept of flexible satellite platform is proposed. According to the feature and function of different devices and software in the satellite platform, the satellite system architecture can be divided as shown in Fig. 1. Based on the architecture, different devices and software modules are integrated into a satellite system in simple ways according to the mission requirements, and the rapid application goal can be achieved.

The payload module can be directly chosen and rapidly assembled or replaced according to mission requirements. The payload module could be different cameras or radar observing the ground or the space, scientific experiments and communication antennas, etc.

Flexible satellite platform includes hardware modules and component-based software modules in the satellite system, which is the focus of this paper. The flexibility of the satellite platform appears in its strong ability to adapt to different payloads and various flight missions.

Component-based software, namely the satellite onboard software in component-based form, is divided with respect to standardized software architecture, which can be replaced and reconfigured according to the requirements of different satellite. The rapid integration and Plug and Play of the system software can be acquired by data transmission protocol between software components.

Reconfigurable module is the core to achieve satellite rapid assembly or device replacement. It can quickly adapt to diverse universal modules such as standardized devices, boards, and so on. It adapts to different interfaces or different function requirements by software configuration with a fixed physical structure, which is thus not required to be redeveloped according to specific tasks.

Universal module refers to commercial single unit, standardized functional boards, etc. Universal module is selected from the product catalog according to mission requirements during the satellite design, which doesn't require any changes or configuration. The universal modules include standardized board of power control unit, power distribution control unit and thermal control unit, commercial single units of star sensors, fiber optic gyroscopes, flywheels and magnetic torquers, the standardized product of antennas, batteries and solar panel, etc.

The custom-built system should be adopted or redesigned during different satellite design according to the alterations of the payload and mission, such as structure, thermal control, cable net, etc.

Based on the classification principles of satellite architecture above, the design procedure of the flexible platform is proposed as follows:

(1) Considering the requirements of the mission and payloads, the optimal configuration parameters of universal modules are determined with the universal modules selection from the product catalogs. The optimal configuration parameters are obtained by applying multi-disciplinary multi-objective optimization design method. The optimization treats the overall functionality and performance as the objective, configuration parameters of common modules as optimization design variables, overall requirements of the micro-satellite project as the constraint conditions.

(2) The reconfiguration modules are dynamically reconfigured according to the function and interface requirements of the selected modules at the first step. It should not only satisfy mission requirements but also match the specific interfaces of payloads and universal modules.

(3) The component-based satellite onboard software is built by selecting the corresponding software components and device drivers from the component library according to the satellite platform hardware configuration and mission requirements.

(4) The custom-built system is designed optimally to complete the satellite overall design considering the mission and payload requirements and the configuration scheme of reconfigurable modules and universal modules.

3. Application of plug and play in flexible micro-satellite platform

In order to achieve rapid integration and component replacement of satellite system, the satellite integrated electronic system is designed to be a reconfigurable module to realize the plug and play feature of universal modules. By reconfiguring the interface of the reconfigurable module, various universal modules with different interfaces can access to the satellite system quickly. Application of standardized information network can achieve rapid data exchange between universal modules and central computer. The device identification system can be used to identify the hardware module automatically. Through these technologies the entire satellite platform network can be build rapidly.

3.1. Hardware architecture based on plug and play

The key point to achieve satellite rapid integration is to build an integrated electronic system to satisfy the requirements of plug and play. The information network standardization and the ability of interface reconfiguration for universal module fully exhibit the system flexibility capabilities, which make the rapid satellite design task feasible to realize.

Fig. 2 illustrates the topological structure of reconfigurable integrated electronic system based on the above design concept. The structure includes a central computer, lower machines consisted of reconfigurable functional units and single machines with standard interface, as well as an information network.