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An optimization tool for satellite equipment layout

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Abstract

Selection of the satellite equipment layout with performance constraints is a complex task which can be viewed as a constrained multi-objective optimization and a multiple criteria decision making problem. The layout design of a satellite cabin involves the process of locating the required equipment in a limited space, thereby satisfying various behavioral constraints of the interior and exterior environments. The layout optimization of satellite cabin in this paper includes the C.G. offset, the moments of inertia and the space debris impact risk of the system, of which the impact risk index is developed to quantify the risk to a satellite cabin of coming into contact with space debris. In this paper an optimization tool for the integration of CAD software as well as the optimization algorithms is presented, which is developed to automatically find solutions for a three-dimensional layout of equipment in satellite. The effectiveness of the tool is also demonstrated by applying to the layout optimization of a satellite platform.

Keywords: Constrained layout optimization; Satellite; NSGA-II; Trade-off solutions

1. Introduction

One of the main tasks involving the development of a new spacecraft is how to distribute its equipment. This problem is first addressed in the conception phase of the design and is traditionally carried out by a group of system engineers. Usually, the initial positioning is done based on the engineers' experience, followed by an analysis stage in which the design performance and constraints are verified (Cuco et al., 2015). This process always takes a lot of time and usually leads to a suboptimal layout design. The layout optimization method which was developed to automatically find solutions for the layout of equipment in spacecraft could greatly improve efficiency and lead to better solutions for the layout.

Over the past few years, a lot of researchers have conducted an in-depth study of spacecraft layout problem. Ferebee and Powers (1987) first used a numerical optimization method to address the spacecraft equipment layout problem. Tanner and Fennel (1991) adopted a layout assistant system to solve the equipment placement problem in the Space Station Freedom. In the next few decades, Tang and Teng (1999), Andrea and Silvano (2002), Wang et al. (2002), Li et al. (2004), Huang et al. (2006), Zhang et al. (2008), Mhand and Rym (2009), and Qin and Liang (2016) studied a series of optimization methodologies to deal with the layout problem of a spinning telecommunication satellite. Most of these works focused these specifically on space utilization and mass characteristics of the system. Stokes and Swinerd (2004, 2005) found that the consideration of the internal arrangement of equipment is an extremely important means of improving the survivability of a satellite in the space debris environment. Qin and Liang (2017) studied the two-dimensional layout optimization of the spinning satellite cabin considering the space debris impact risk. An impact risk index was developed to

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quantify the risk to a satellite cabin of coming into contact with space debris.

In many years, the study of the layout problem only stayed at the level of algorithm. There is still a long distance from the actual engineering applications, because the spacecraft layout problem in the project is usually a three-dimensional problem rather than a two-dimensional problem. Baier and Pühlhofer (2003) developed a general framework for the integration of Computer Aided Design (CAD) tools as well as the optimization algorithms to optimize the layout of spacecraft equipment, which provided a practical method for us to solve the three-dimensional spacecraft layout problem. Cuco et al. (2015) proposed an automatical tools for find layout solutions in the three-dimensional layout of equipment in spacecraft. It includes mass, inertia, thermal and subsystem requirements and geometric constraints using a multi-objective approach that combines CAD and optimization tools in an integrated environment. Fakoor et al. (2016) developed an efficient Spacecraft Component Adaptive Layout Environment (SCALE) by integration of some modeling, FEM, and optimization software. SCALE automatically provides optimal solutions for a three-dimensional layout of spacecraft subsystems with considering important constraints such as center of mass, moment of inertia, thermal distribution, natural frequencies and structural strength.

In this paper, an optimization tool for satellite equipment layout is presented. Compared with the tools proposed by Fakoor et al. and Cuco et al., the space debris impact risk assessment model developed to evaluate the impact risk that the spacecraft was subject to in all directions was coupled in the unified environment of iSIGHT. That is to see the tool can provide a capability to assess the space debris impact risk and a means to optimize the debris protection strategy by designing the overall layout of a spacecraft. We discuss the following main objectives that engineers must usually consider when designing the equipment layout for a satellite cabin: (i) C.G. offset of the satellite cabin, (ii) cross moments of inertia of the packing system, and (iii) space debris impact risk of the system. The proposed methodology is treated using the Pareto approach, which allows a better knowledge of the solution space and to examine the trade-off relationship between the C.G. offset, the cross moments of inertia and the space debris impact risk index. We use an example to verify the effectiveness of the tool.

This paper is organized as follows. In Section 2, we describe the proposed tool corresponding to the three-dimensional equipment layout for a satellite cabin. This section presents an optimization tool for the integration of CAD tools as well as the optimization algorithms to optimize the layout of spacecraft equipment. Section 3 presents the objective functions and constraints for the layout problem. Section 4 presents the results obtained through our optimization tool. The trade relationship between the C.G. offset, the cross moments of inertia and the space debris impact risk index is examined. Summaries of this study are made in Section 5.

2. Proposed tool

In this section, an optimization tool for the integration of CAD tools as well as the optimization algorithms to optimize the layout of spacecraft equipment has been presented. This tool will provide the possibility finding optimal solutions for a three-dimensional layout of spacecraft automatically and is able to consider the main goals that usually taken into account by engineers when placing the location of equipment, such as the C.G. offset, moment of inertia and the space debris impact risk in acceptable time.

The internal structure of the tool is shown in Fig. 1. As shown in Fig. 1, three software which include EXCEL, MATLAB and SOLIDWORKS are coupled together in the unified environment of iSIGHT and have data transfer with each other. The iSIGHT provides an open platform integration, of which the progress interface is able to integrate various tools, such as the commercial CAD software, manifold finite element analysis software and user-developed procedures. By using iSIGHT, we can automate the data translation and control the execution of these software packages.

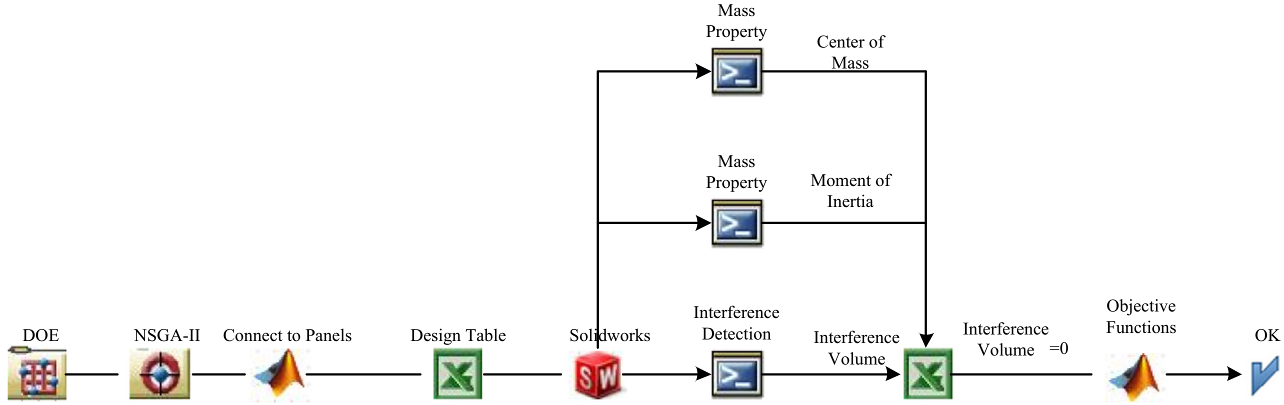

Fig. 1. Internal structure of the tool for satellite equipment layout.

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