Choice of Spacecraft Control Contour Variant with Self-configuring Stochastic Algorithms of Multi-criteria Optimization

Maria Semenkina[1, 2], Shakhnaz Akhmedova[1], Christina Brester[1] and Eugene Semenkin[1]
[1]*Institute of Computer Sciences and Telecommunication, Siberian State Aerospace University,*
Krasnoyarskiy Rabochiy ave., 31, Krasnoyarsk, 660014, Russia
[2]*Institute of Mathematics and Computer Science, Siberian Federal University,*
Svobodnyj ave. 79, Krasnoyarsk, 660041, Russia
semenkina88@mail.ru, shahnaz@inbox.ru, christina.brester@gmail.com, eugenesemenkin@yandex.ru

Keywords: Spacecraft Command-programming Control Contours Modelling, Markov Chains, Effective Variant Choice, Multi-objective Optimization, Evolutionary Algorithms, Self-configuration, Bio-inspired Intelligence.

Abstract: Command-programming control contours of spacecraft are modelled with Markov chains. These models are used for the preliminary design of spacecraft control system effective structure. Corresponding optimization multi-objective problems with algorithmically given functions of mixed variables are solved with a special stochastic algorithms called Self-configuring Non-dominated Sorting Genetic Algorithm II, Cooperative Multi-Objective Genetic Algorithm with Parallel Implementation and Co-Operation of Biology Related Algorithms for solving multi-objective integer optimization problems which require no settings determination and parameter tuning. The high performance of the suggested algorithms is proved by solving real problems of the control contours structure preliminary design.

1! INTRODUCTION

The synthesis of a spacecraft control systems is a complex and undeveloped problem. Usually this problem is solved with more empirical methods rather than formalized mathematical tools. Nevertheless, it is possible to model some subproblems mathematically and to obtain some qualitative results of computations and tendencies that could provide experts with interesting information.

We will model the functioning process of a spacecraft control subsystems with Markov chains. We explain all results with small models and then give illustration of large models that are closer to real system. The problem of choosing an effective variant for a spacecraft control system is formulated as a multi-objective discrete optimization problem with algorithmically given functions. In this paper, we use self-configuring evolutionary algorithms, Cooperative Multi-Objective Genetic Algorithm and Co-Operation of Biology Related Algorithms to solve the optimization problem.

The rest of the paper is organized in the following way. Section 2 briefly describes the modeled system. In Sections 3 we describe models for command-programming control contours. In Section 4 we describe optimization algorithms that have been used. In Section 5, the results of the algorithms performance evaluation on spacecraft control system optimization problems is given, and in the Conclusion section the article content is summarized and future research directions are discussed.

2! PROBLEM DESCRIPTION

If we simplify then we can describe the system for monitoring and control of an orbital group of telecommunication satellites as an automated, distributed, information-controlling system that includes on-board control complexes (BCC) of a spacecraft and the ground-based control complex (GCC) (Semenkin, 2012) in its composition. They interact through a distributed system of telemetry, command and ranging (TCR) stations and data telecommunication systems in each. BCC is the controlling subsystem of the satellite that ensures real time checking and controlling of on-board systems including pay-load equipment (PLE) as well as fulfilling program-temporal control. "Control contours" contain essentially different control tasks

Semenkina, M., Akhmedova, S., Brester, C. and Semenkin, E.
Choice of Spacecraft Control Contour Variant with Self-configuring Stochastic Algorithms of Multi-criteria Optimization.
In *Proceedings of the 13th International Conference on Informatics in Control, Automation and Robotics (ICINCO 2016) - Volume 1*, pages 281-286
ISBN: 978-989-758-198-4

from different subsystems of the automated control system. In this paper we will consider command-programming contours.

All contours are not function dependable and have many indexes that leads to many challenges during choosing an effective control system variant to ensure to all of the control contours. All this problems are multi-objective with criteria that cannot be given in the form of an analytical function of its variables but exist in an algorithmic form which requires a computation or simulation model to be run for criterion evaluation at any point.

In order to have the possibility of choosing an effective variant of such a control system, we have to model the work of all control contours and then combine the results in one optimization problem with many models, criteria, constraints and algorithmically given functions of mixed variables. We suggest using adaptive stochastic direct search algorithms (evolutionary and bio-inspired) for solving such optimization problems. To deal with many criteria and constraints successfully we just have to incorporate techniques, well known in the evolutionary computation community.

To support the choice of effective variants of spacecrafts' control systems, we have to develop the necessary models and resolve the problem of evolutionary algorithms (EA) and bio-inspired methods settings for multi-objective optimization.

3! COMMAND-PROGRAMMING CONTROL CONTOUR MODELLING

The main task of this contour is the maintenance of the tasks of creating of the command-programming information (CPI), transmitting it to BCC and executing it and control action as well as the realization of the temporal program (TP) mode of control (Semenkin, 2012).

Markov chains can be used for modelling this contour because of its internal features such as high reliability and work stability. That is why we are supposing that all stochastic flows in the system are Poisson. If we suppose that BCC can fail and GCC is absolutely reliable, then we can introduce the following notations: λ_1 is the intensity of BCC failures, μ_1 is the intensity of temporal program computation, μ_2 is the intensity CPI loading into BCC, μ_3 is the intensity of temporal program execution, μ_4 is the intensity of BCC being restored after its failure. The graph of the states for command-programming contour can be drawn as in Figure 1.

There are also five possible states for this contour (Semenkin, 2012):

1. BCC fulfills TP, GCC is free.
2. BCC is free, GCC computes TP.
3. BCC is free; GCC computes CPI and loads TP.
4. BCC is restored with GCC which is waiting for continuation of TP computation.
5. BCC is restored with GCC which is waiting for continuation of CPI computation.

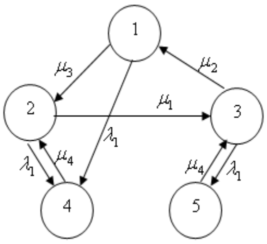

Figure 1: The states graph of the Markov chain for the simplified model of the command-programming control contour (Semenkin, 2012).

After solving the Kolmogorov's system:

$$\begin{gathered}
P_1\cdot(\lambda_1+\mu_3) - \mu_2\cdot P_3 = 0, \\
P_2\cdot(\lambda_1+\mu_1) - \mu_3\cdot P_1 - \mu_4\cdot P_4 = 0, \\
P_3\cdot(\lambda_1+\mu_2) - \mu_1\cdot P_2 - \mu_4\cdot P_5 = 0, \\
P_4\cdot\mu_4 - \lambda_1\cdot P_1 - \lambda_1\cdot P_2 = 0, \\
P_5\cdot\mu_4 - \lambda_1\cdot P_3 = 0, \\
P_1 + P_2 + P_3 + P_4 + P_5 = 1.
\end{gathered}$$

we can calculate the necessary indexes of control quality for the command-programming contour:

1. $T = P_1/(\mu_2\cdot P_3) \rightarrow \max$ (the duration of the independent operating of the spacecraft for this contour);
2. $t_1 = (P_3+P_5)/(\mu_1\cdot P_2) \rightarrow \min$ (the duration of BCC and GCC interactions when loading TP for the next interval of independent operation of the spacecraft);
3. $t_2 = (P_2+P_3+P_4+P_5)/P_1\cdot(\lambda_1+\mu_3) \rightarrow \min$ (the average time from the start of TP computation till the start of TP fulfillment by BCC).

Optimization variables are stochastic flow intensities, i.e., the distribution of contour functions between BCC and GCC. If they are characteristics of existing variants of software-hardware equipment, we have the problem of effective variant choice, i.e., a discrete optimization problem.

Recall that obtained optimization problem has algorithmically given objective functions so before the function value calculation we must solve the system of equations.