The Choice of the Operability Restore Tools of Rational Control Objects

Olena Havrylenko, Anatoly Kulik and Andriy Chukhray

National Aerospace University "Kharkiv Aviation Institute", Kharkiv, 61070, Ukraine

Abstract

Argumentation is presented on the need to adapt spacecraft orientation systems in emergency situations through rational control. Rational control is based on the intelligent diagnostic and recovery functions automation. The problem statement of choosing restoration tools in the block diagram of a rational control system is considered. The dynamic knowledge base of recovery tools is presented. The methods for choosing the tools of restoring of rational control object operability under destabilizing influences are described.

Keywords [1]

rational control object, efficiency, destabilizing effect, dynamic knowledge base, restoration, choice.

1. Introduction

The space missions' duration increase has led to the emergence of new scientific and technical problems to ensure the operability of onboard systems and in particular spacecraft attitude control systems. In a long-term space flight in addition to the traditional perturbing effects of the external environment, failures, malfunctions and equipment faults of the internal environment affect the attitude systems. External and internal influences are essentially destabilizing factors that disrupt the orientation systems performance. To parry destabilizing influences more developed of orientation systems functional tools are needed that provide autonomous and operational adaptation to changing operating conditions. Such adaptation can be provided by automating such intellectual abilities of a person as the ability to find the cause of emergency situations by consequences, i.e. to diagnose and, knowing the diagnosis, to choose the tools of restoring the efficiency of the orientation system.

Attempts to create artificial intelligent tools capable of perceiving information and processing it reasonably, as well as making effective decisions, led to the need to develop special cognitive agents of architectures, as well as a mathematical apparatus for their description and design. Examples of the first successful cognitive architectures are the ACT and SOAR systems based on production rules. The cognitive structure PRS (Procedural reasoning system) was used in the Sydney airport air traffic control system [1, 2].

Known examples of the use of cognitive agents and structures in space vehicles [3, 4] are fragmentary attempts to solve particular problems of intellectualization of individual functions. So, for example in [3] authors identify deep learning in space as one of development directions for mobile and embedded machine learning. They collate various applications of machine learning to space data, such as satellite imaging, and describe how on-device deep learning can meaningfully improve the operation of a spacecraft, such as by reducing communication costs or facilitating navigation. The paper [4] aims at introducing the most relevant characteristics of deep learning methods and artificial neural networks for spacecraft dynamics control, guidance and navigation. A more systematic approach to adaptation through intellectualization is to use a new principle of health management -

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EMAIL: o.havrylenko@khai.edu (O. Havrylenko); anatoly.kulik@gmail.com (A. Kulik); achukhray@gmail.com (A. Chukhray)
ORCID: 0000-0001-5227-9742 (o. Havrylenko); 0000-0001-8253-8784 (A. Kulik); 0000-0002-8075-3664 (A. Chukhray)

the principle of management by diagnosis. The use of this principle allows us to formulate a new structure of rational control [5]. This structure has all the necessary features of a physical intelligent agent and allows to maintain the efficiency of objects of rational control in an autonomous mode under destabilizing influences.

The object of rational control in this structure must have the properties of diagnosability and recoverability, which make it possible to ensure adaptability to destabilizing influences.

A necessary condition for the recoverability of an object of rational control is the absence of an excess amount of reserve tools. After fault state diagnosis is stated, one of several possible tools is required to implement procedures for restoring the operability of a rational control object.

The paper presents the results of solving the problem of choosing the tools of restoring the efficiency of a rational control object using a dynamic knowledge base of possible diagnoses and the corresponding tools of restoration.

2. Block diagram of an attitude rational control system

Consider, using the example of a block diagram of a rational orientation control system, the problem statement of choosing recovery tools.

To control the attitude of a spacecraft under conditions of destabilizing effects, according to the principle of control by diagnosis, a certain composition of functional elements is required (Figure 1).

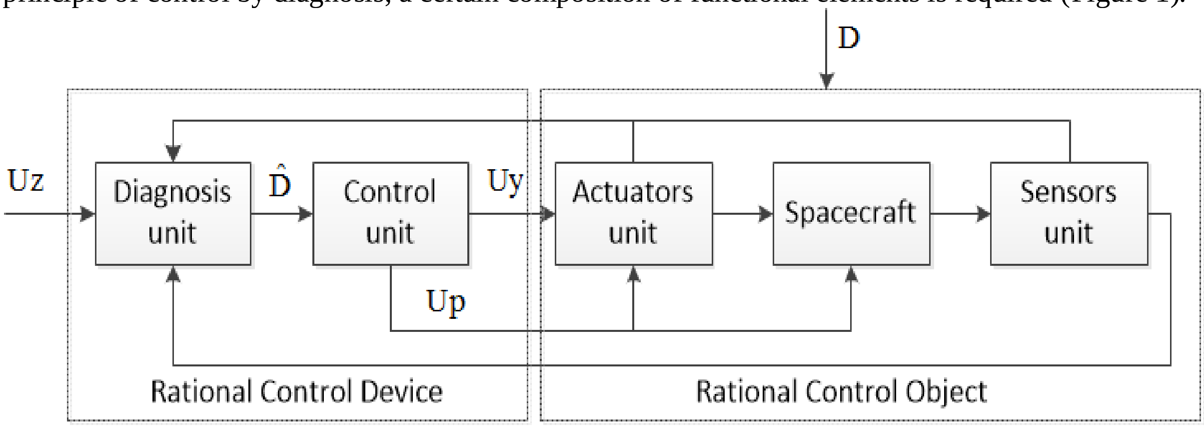

Figure 1. Block diagram of a rational control system

For rational control of the spacecraft relative to the center of mass, a redundant structure sensor unit and a redundant structure drive unit are used. The object of rational control is affected by many types of destabilizing influences that violate its orientation, i.e. workable state. The operability status is analyzed in the diagnosis unit using information from the sensor unit and drive unit, and a diagnosis $\widehat{D}$ is formed [5]. The result of the diagnosis received by the control unit, where, depending on the diagnosis, a specific recovery tool is selected from a variety of possible ones and introduced into the process of restoring operability via the control channel using the Uy impact or via the reconfiguration control channel using the Up impact [5].

Further in the control unit upon information being received about a appeared fault in the rational control object, a specific tool among the recovery tools available on the spacecraft board should be chosen promptly and in such way the operability is restored.

3. Dynamic knowledge base

When designing an object of rational control for each type of destabilizing effect $\mathrm{d_i} \in \mathrm{D}, \mathrm{i} = \overline{1, \mathrm{q}}$ tools of parrying it $\mathrm{v_j} \in \bar{\mathrm{v}}, \mathrm{j} = \overline{1, \mu}$ are formed based on the possibilities of the design, the existing structural redundancy, taking into account the limitations of weight and size, energy and cost. Mathematically, this can be represented using the mapping $\mathrm{F}: \mathrm{D} \rightarrow \mathrm{v}$. This relationship can be represented graphically using Table 1, where the types of destabilizing effects d_i are placed by rows, and the tools of recovery v_j used to neutralize them are placed by column. In accordance with the requirement of multifunctionality such tools are chosen that can parry several types of d_i, which is reflected by the Boolean variable σ_{ij}, which takes the value "1" if it is possible to neutralize the type of destabilization d_i using the recovery tool v_j or "0" if not.

Table 1
Destabilizations-recovery tools relationship

Kinds	Recovery tools				Level
	v_1	v_2	…	v_μ	
d_1	σ_{11}	σ_{12}	…	$\sigma_{1\mu}$	c_1
d_2	σ_{21}	σ_{22}	…	$\sigma_{2\mu}$	c_2
.	.	.	…	.	.
.	.	.	…	.	.
.	.	.	…	.	.
d_q	σ_{q1}	σ_{q2}	…	$\sigma_{q\mu}$	c_q
Rank	r_1	r_2	…	r_μ	c_0

Parameters r_j, numerically equal to the count of "1" in the column, characterize the rank of recovery tools. The more types of destabilization d_i can be neutralized by using the tools v_j, the higher its rank r_j.

The parameter c_i, numerically equal to the sum of "1" in the row, characterizes the destabilization d_i recoverability level. The higher c_i, the more tools available for rational control object operability recovering in the case of the destabilizing effect d_i appearance. The lower c_i, the smaller amount of tools v_j are available for restoring working order. Parameter c_0 characterizes the general level of the object recoverability and is equal to the sum of the ranks r_j.

The Table 1 is formed from the condition of satisfying the following criteria of recoverability: $\forall c_i \geq c_t, i = \overline{1, q}$ and $\forall r_j \geq r_d, j = \overline{1, \mu}$. Here c_t is the required value of the recovery level, based on the tactical and technical requirements for the attitude control system, and r_d is the allowable rank of recovery tools, based on the limitations on operational characteristics.

In the course of functioning of system of rational management Table 1 should reflect the current state of available recovery tools, i.e. each time v_j is selected and used, the recovery tool removes the corresponding column from the table and recalculates the level values c_i. In fact, the table is a dynamic structure of the knowledge base of recovery tools for types of destabilizing effects of the form $d_i \in D$. The production rules in the equivalent format of the production knowledge base for restoring operability are formed according to the rows of the table as follows: “if the diagnosis is d_i, then available recovery tools correspond to it are those, for which $\sigma_{ij} = 1$”. Further it is necessary to select only one from these recovery tools for its use in the procedure for restoring the operability of a rational control object.

4. Tools choice

For each row of the dynamic knowledge base, there is a subset $V_k \subset V$ of recovery tools. From this subset, it is necessary to choose one tools $v_j \in V_k$, which will be the best from the point of view of some criterion. Depending on the criterion, an appropriate algorithm for choosing the best recovery tool is also formed.

4.1. Single-criterion choice

The rank numerically reflects the weight of each recovery tool. To each d_i matches a subset V_k and, accordingly, a subset of ranks $R_k \subset R$, where R is the set of all ranks r_j . The set R is the set of natural numbers. Among these numbers it is necessary to find one that satisfies the selected criterion.

In traditional practice, the use of redundant recovery facilities on spacecraft applies the principle of frugality. This principle lies in the fact that to parry the current contingency, the simplest backup tools is used, i.e. the lowest ranking agent, assuming that the worst off-nominal situations may be in later phases of the flight and will require higher ranking recovery agents to parry them. Therefore, in relation to the Table 1 needed nonnumeric subsets R_k to find the lower numerical edge. Mathematically, this is described as follows: $\forall r_j \in R_k \; r_{min} < r_j$. Then v_{min} is the optimal tool for recovery in a current case.

To find the smallest number in the R_k subset, it is necessary to use a method that allows performing search in the optimal way. For the dynamic knowledge base the criteria for method optimality might be time and memory storage volume.

If the count of tools for recovery is more than 100 and information renewed rarely then it could be better to store data sorted by rows in ascended order according to r_j. In this case first founded $\sigma_{ij} = 1$ in a row d_i will give the number j of tool v_j with the minimal rank. Additional memory is unneeded, time complexity of search will be O(n) and processing time will be less in better cases. However it is need additional operating time, when knowledge base is restored.

In other cases it will be reasonable just to combine search in a row d_i using both criteria: $\sigma_{ij} = 1$ and $r_{min} < r_j$. Then procedure of search will be following:

$r_{min} = max\ \_natural\_number,\ min = 0$
$i = current, j = 1$
Repeat for $j <= \mu$
If $\sigma_{ij} = 1$ and $r_j < r_{min}$ then $r_{min} = r_j$, $min = j$
$j = j + 1$

After this procedure v_{min} is the optimal tool for recovery destabilization d_i. Additional memory needs only for four temporary numbers. Time of processing could be estimated as O(n) in any case.

4.2. Multi-criteria choice

It is great possibility that the rank of several tools in the subset V_k could be the same. So we may improve the automatic recovery tool choice in the rational control system by adding some other criteria. As shown in Table 2 there are several parameters that could be estimated for each tool:

- cost of device or of its exploitation (S),
- energy need for operation of a unit (E),
- percentage of device loading in the system (P).

Table 2
Destabilizations-recovery tools relationship

Kinds	Weihts	Recovery tools				Level
		v_1	v_2	...	v_μ	
d_1	-	σ_{11}	σ_{12}	...	$\sigma_{1\mu}$	c_1
d_2	-	σ_{21}	σ_{22}	...	$\sigma_{2\mu}$	c_2
.	.	.	.	...	.	.
.	.	.	.	...	.	.
.	.	.	.	...	.	.
d_q	-	σ_{q1}	σ_{q2}	...	$\sigma_{q\mu}$	c_q
Rank (R)	w_1	r_1	r_2	...	r_μ	c_0
Cost (S)	w_2	s_1	s_2	...	s_μ	-
Energy (E)	w_3	e_1	e_2	...	e_μ	-
Percentage (P)	w_4	p_1	p_2	...	p_μ	-

Other criteria might be introduce as well to have possibility use the whole set $K = [R,\ S,\ E,\ P\ ...]$ of them or some subset $K' \subset K$.

In any case we have a statement of the multi-criteria problem of choosing the best option $v^{opt} \in V_k$ according to the set of criteria K. It is usually solved in classical decision-making theory using one of the developed methods [6-8]. In our case all the criteria from K should be minimized and each one may be weighted by natural number: $K \to W, W = [w_1, w_2, \dots w_\eta,]$. For instance, in Table 2 $\eta = 4$.

The main advantage of the methods of multi-criteria decision-making is that they allow obtaining the best alternatives having contestant criteria represented in different scales (from rang to absolute) close to those that could be chosen by excellent expert human who is objective without any biases. But it must be mentioned that the major procedures are automated, not automatic, and need a lot of customizations during the process [7]. Moreover any method does not guarantee the choice of one best alternative – mostly it is subset $V^{opt} \subset V_k$ rather than unique element [8]. Therefore the combination of methods should be applied for recovery tool choice procedure in the rational control system. Such combination must have minimum preliminary customizations and possibility of no intrusions into the process of choice. Whereas algorithm must be simple enough from the point of view of time running but give objectively chosen option.

In the work it is propose to apply in parallel modified method ELECTRE – ELECTRE GR [9] and Waited Sum Method [10] with the simple form of the objective function:

$$F(v_j) = \sum_{k_i \in K} -w_j k_i(v_j)\,,\ v_j \in V_k. \qquad (1)$$

The scheme of the proposed method is represented on Figure 2.

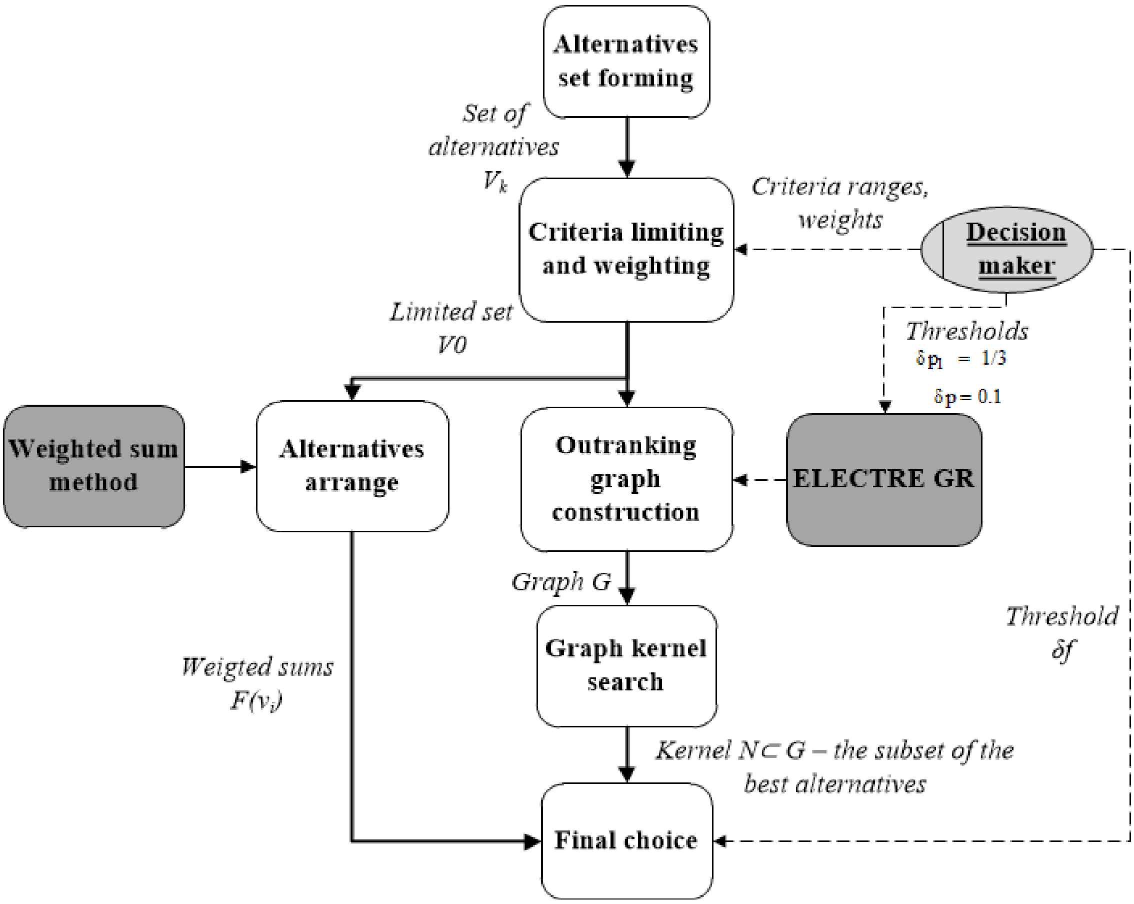

Figure 2. Multi-criteria method scheme

During final choice the weighted sums $F(v_i)$ for the alternatives $v_i \in N$ getting by ELECTRE GR method could be presented to a decision maker for his analysis. In a case of automatic procedure:

$$v^{opt} \in N \mid F(v^{opt}) \to min\,. \qquad (2)$$

In the other hand as shown on Figure 2 after applying WSM we can get not unique optimal solution, but subset

$$V^{opt1} \subset V_k \mid \forall\, v^{opt} \in V^{opt}\ F(v^{opt}) < \delta f, \qquad (3)$$

where δf is a threshold given by the decision maker or set by default in a case of automatic procedure:

$$\delta f = \min(F) + 0.1(\max(F) - \min(F)). \quad (4)$$

In this case the subset of the best tools for restore will be found as:

$$V^{opt} = V^{opt1} \cap N. \quad (5)$$

The rational control system based on such techniques will be able to run in pure automatic mode after criteria ranking. The thresholds as it was mentioned may be set by default. The best final alternative could be define in two ways:

- using (2) and procedure as in the case of single-criterion choice, defined above;
- using (3) and (5) with gradually changing δf beginning from maximum until $|V^{opt}| = 1$.

5. Conclusion

The theoretical studies carried out on the dynamic knowledge base processing for tools choosing have shown the possibility of the spacecraft control intellectual procedure automation. The results obtained during research allow proceeding to the development of software modules for a dynamic knowledge base and the choice of tools for restoring the operability of rational control objects.

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