Managing the protection of autonomous objects: construction basics

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Abstract

The principles of constructing an intelligent control system for the protection of an object are developed. The intelligent control system solves computational and intelligent problems using models and tools located at the control object and an external control center. The solution for controlling the protection of a spacecraft in orbital flight is presented.

Keywords 1

Intelligent system, spacecraft, machine learning, knowledge base

1. Introduction

The tasks of detecting a possible mechanical impact threat, maintaining their own operational catalog, predicting the level of a threat (for example, in accordance with the dangerous approaching criterion), evaluating the results of a forecast with the formation of warning call about a dangerous approaching, possible collision and taking measures to protect the object are important for the objects of the class of autonomous long-term functioning objects. The task of controlling the spacecraft (SC) protection with long-term operation is one of them.

To implement effective protection against a threat of collision with other space objects (first of all, uncontrolled space debris (SD) particles), we must generate information on SC board. This information consists:

- information about the detection of dangerous space objects in the form of a warning signal 'Dangerous approaching'. This information is generated on all detected SD elements with the parameters of the mutual motion of space objects and the time before a possible collision. The criterion for reproduction a signal is the achievement of a given calculated value of the possible approach for a pair of orbital objects in space.
- information about the damage danger in a collision in the form of a warning signal 'Danger of SC damage'. The criterion for reproduction a signal is the calculated value of the local possible area of SC, which is exposed to the impact in a collision with a space object.
- information about the predicted consequences of SD impact. This is information about the predicted criterion of SC damage for taking measures to connect an effective safety barrier.
- information about the effectiveness of measures implemented on board (security barriers) when they are implemented in specific conditions.

All information about the detected SD objects is sent to the ground control complex (GCC) in conditions of mutual visibility between GCC and SC. An in-depth analysis, forecasting and development of measures to improve the survivability and operational reliability of the spacecraft are carried out on GCC with the use the developed experimental-calculation and computer models.

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2. The Construction Principles of Intelligent System

The structural organization of modern intelligent systems, based on the provisions of the artificial intelligence theory, operations research and automatic control, was developed in 1989 by J. Saridis [3]. The following layers of information processing (intelligence layers) are provided for it:

- event forecasting layer;
- self-learning and adaptation layer;
- layer of work with databases of events, knowledge and formation of decisions;
- executive layer.

Each of the indicated layers has a functional specificity and can consist of several levels in a real system. In this case, classical models of automatic control systems are used in the lowest executive layer. As a rule, this is a hard execution of the built-in hardware-level commands to connect the selected security barrier. The rest of the higher rank layers must satisfy the information technology requirements for working with knowledge and the capabilities of such models.

Depending on how many layers of the intelligence system has, the following classification of intelligent systems for providing and controlling the SC protection has been introduced:

- the system, containing two intelligence layers, has a degree of intelligence 'in small';
- the system, containing three intelligence layers, has a degree of intelligence; 'in large';
- the system, containing four intelligence layers, has a degree of intelligence; 'generally'.

The fundamentals of the construction and operation of the integrated intelligent information system (IIIS) for SC security control take into account the features of building the knowledge base of the intelligent system [2] and are represented by the following propositions:

1. The multilevel hierarchical structure principle, built in accordance with the IPDI (Increasing Precision with Decreasing Intelligence) rule of the theory of intelligent machines with a degree of at least two intelligence layers.

This principle ensures SC safety through operational forecasting using timely (trained) self-learning knowledge bases, working with event and knowledge bases, and forming adaptive control exposures using intelligent models implemented on GCC. The results of high-precision experimental and computational modeling are used by groups of experts with systemic knowledge and intuition. This principle also ensures SC safety using the knowledge base included in the intelligent prediction module on SC. In this case, the inaccuracy of knowledge about the situation can be compensated at the expense of the presence of intelligence in the system and the corresponding control algorithms.

2. The principle of having a built-in forecasting mechanism for:

- environmental conditions associated with the possible SD impact;
- the results of SD impact identified with the SC damage criteria;
- evaluating the effectiveness of security barriers for various conditions.

This principle allows avoiding a situation associated with external mechanical threats, for which there are no solutions due to temporary and other restrictions on the operation of mechanisms forming control exposures and/or connect a safety barrier. This principle is especially important for areas of autonomous operation of SC in orbit.

The ability to predict the conditions and results of exposure to SD allows us to formulate another principle. The implementation of this principle will prevent serious damage, that is, the assumption of the worst case. The principle involves the study of all predictable situations, and in accordance with this principle, it is necessary to focus on the most adverse conditions.

3. The continuity functioning principle (possibly with some loss of quality or efficiency) in the event of a break in connections and the impossibility of receiving control actions from the higher levels of the system hierarchy.

This principle establishes a partial decrease in the intelligence level, but not the termination of the functioning for the system as a whole. The presence of semantically stable models for predicting damage and assessing the effectiveness of the implemented barriers (knowledge base) on board ensures the autonomous operation mode for SC and the maximum survivability of SC as a whole.

The structural diagram of the IIIS is shown in Figure 1 [1].

The functional diagram of the spacecraft protection control using the onboard facilities and the GCC facilities is shown in Figure 2.

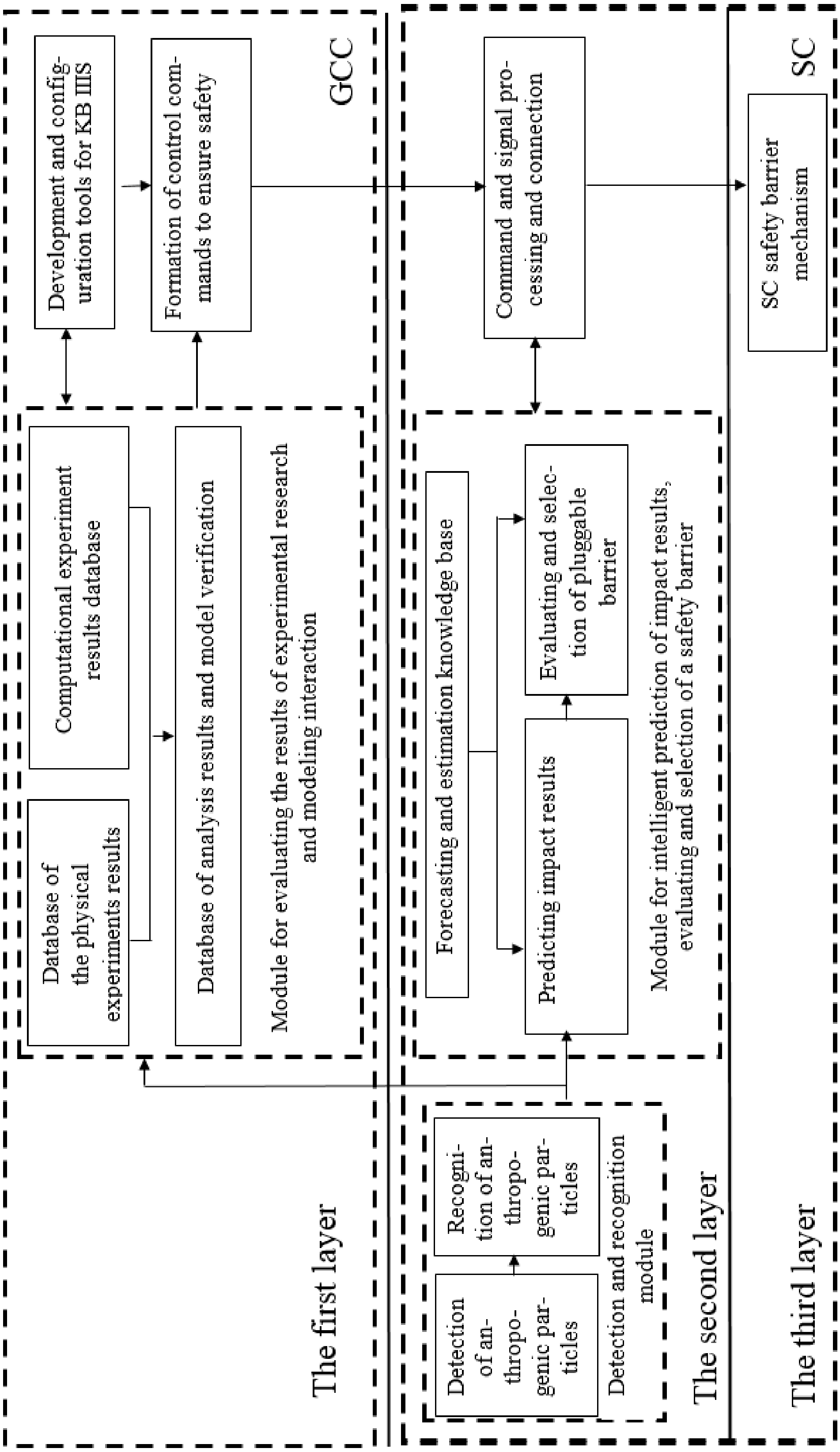

Figure 1: The hierarchical structure of IIIS for the formation of SC operational control solutions to prevent a dangerous approach and collision with SD

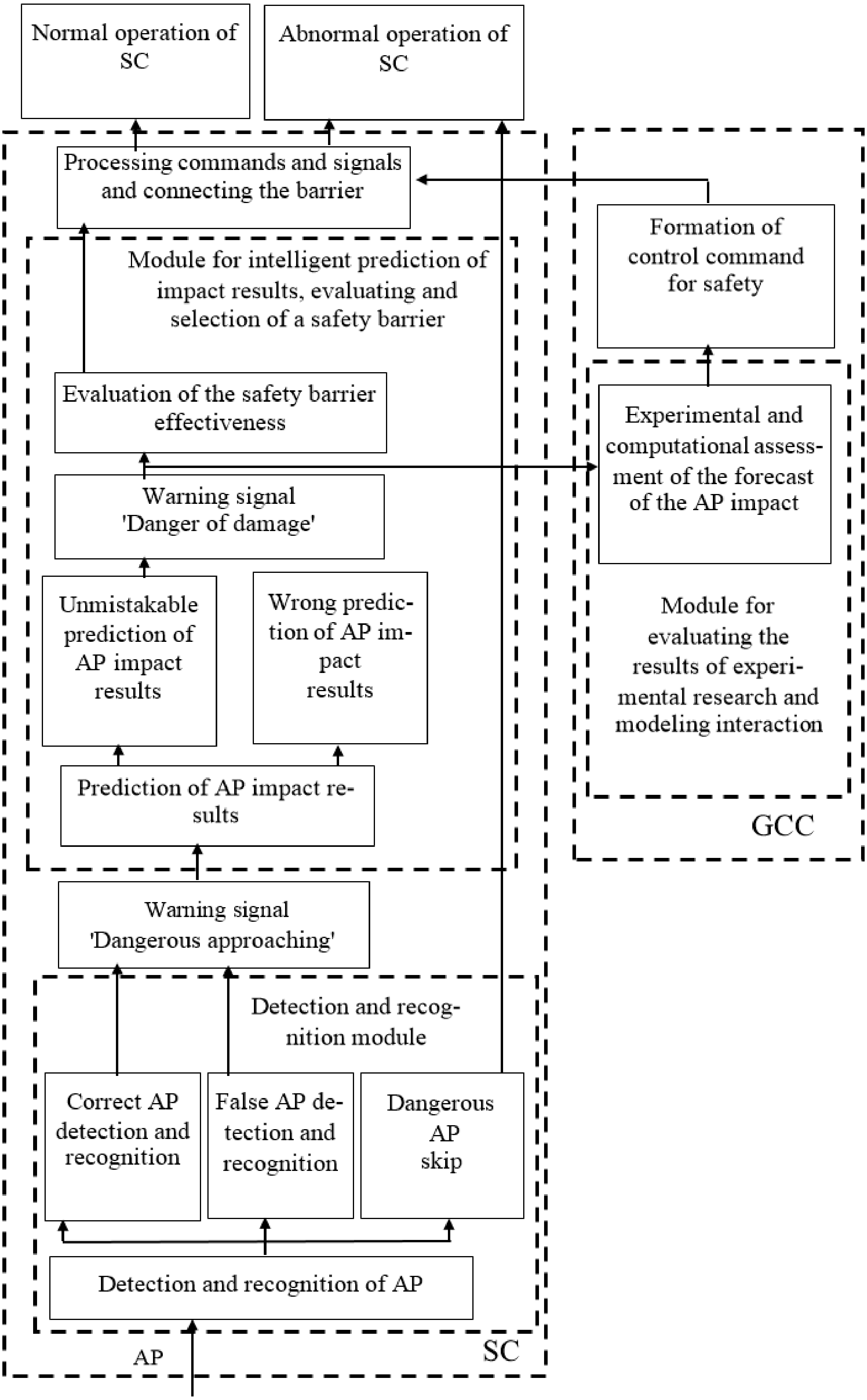

Figure 2: Functional diagram of SC protection control by on-board facilities and GCC equipment

The detection and recognition module of SD objects, which is part of the IIIS, solves the problem of spatial selection, detection, recognition of SD and the assessment of its parameters, such as mass-dimensional characteristics, motion parameters and distance from the SC, estimated time to collision.

On the first layer of the IIIS, the tasks of predicting events, building and maintaining the knowledge base in an up-to-date state, and automated development of proposals for increasing the survivability and operational reliability of SC are solved. At this level, the SC control is carried out via the command radio link with the available time for analysis, preparation and issuance of commands and control programs. Computational-experimental and computer analysis of the stress-strain state of materials and SC structures taking into account mechanical and thermal loads, the analysis of criteria and conditions for the SC damage occurrence are carried out by the module for evaluating the results of experimental studies. and interaction modeling. This module also evaluates the durability of materials to forming and progression of crater and fracture. The specified analysis using the developed computational-experimental and computer models makes it possible to detail the forecast of events and develop reasonable proposals for protective measures.

In addition, the development and training environment of the IIIS knowledge base is implemented on the top layer. Here, the development of logical-linguistic models for knowledge representation and the use of neural network technology for their adjustment are carried out. The body of knowledge embed in the learning process of this structure is determined by setting the coefficients of inter-element relationships and allows for reliable identification of the presented examples. In this case, the most important feature of neural network structures is high speed, achieved due to the parallel processing of information in their hardware implementation [4]. A distinctive feature of teaching knowledge base is the presence of the second stage. It solves the inverse recognition problem by adjusting the values of the input parameters through the gradient of the error function at the network input for each of the damage criteria. For this, the generated sets of values of the input parameters are fed to the trained network input. With the given damage criterion and the result given by the network, the gradient of the error function is calculated by the network input parameters and by the technology of the method of loaded dual networks. In accordance with the values of the gradient elements, the values of the input parameters change in the direction of error decreasing, which makes it possible to iteratively obtain sets of input vectors that generate the required result. At the same time, the synaptic network map configured in the previous step remains unchanged.

The second layer of IIIS is designed to predict events, as well as clarify the effectiveness and connect the safety barrier in an automatic mode. For this, the module for intelligent prediction of impact results, evaluating and selection of a safety barrier has been developed. The key element of the layer is the knowledge base, which is kept up to date by taking into account all changes in the subject area involved in its training. The fuzzy inference mechanism is implemented using the knowledge stored in the knowledge base. The membership function maximum determines the most probable predicted damage criterion.

At the second level, for the selected criterion, estimates of the effectiveness of all barriers that are associated with the identified damage are refined. Refinement is carried out automatically, taking into account the available and required resources and the reliability of protection.

The third layer of IIIS includes many ready-to-connect safety barriers. Safety barriers implemented on SC in the form of functions, products, materials, software, etc., are designed to prevent, stop or slow down the development of a dangerous situation. All of them will be executed according to a rigid program and a command to connect them is required [5].

A distinctive feature of the IISO is to ensure the SC autonomous functioning. The tasks of detecting, recognizing, assessing the danger of SD, predicting the results of its impact on SC are automatically solved in the cycle of the on-board computer, adequately to the current situation. It also evaluates the effectiveness of security barriers and implements the protection of the SC from SD.

3. Conclusions

The developed design principles make it possible to implement fast and slow control loops in the protection systems of an autonomous object subject to external mechanical stress.

The intellectual component implements a fast control loop that estimates the threat level on a real scale and makes it possible to form an effective facility protection mechanism.

A mechanism has been developed. It implements forecasting of the most dangerous input influences in the process of adjusting the IIIS knowledge base in order to use ground-based high-precision experimental-calculation and computer models. These models allow in-depth analysis, forecasting and development of measures to improve the survivability and operational reliability of SC.

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