ROCKET-SPACE DEVICE ENGINEERING AND INFORMATION SYSTEMS
Vol. 3, Iss. 1, 2016, pp. 2–9

Using a Systematic Approach to Solving the Problematic Issues of Functioning of the Automated Complex of Programs for Ballistic and Navigational Support of GNSS Spacecraft Missions

V.V. Betanov[1], V.K. Larin[2]

[1]doctor of engineering science, professor, [2]candidate of engineering science
Joint Stock Company "Russian Space Systems", Russia
e-mail: betanov_vv@spacecorp.ru

Abstract. The article describes the general provisions of the systematic approach to the study of the problems arising in the application systems for data processing. A thesis that the investigated systems have a hierarchical structure combining a certain amount of counterparts is taken as a basis. Therefore, the solution for the system under analysis should be in identifying the inconsistencies between the normal operation being on the same or different hierarchy levels and defining the method of solution depending on the problem structure. A step-by-step technology in the form of successive stages of solution is proposed in the frames of a systematic approach. A work of the automated complex of programs for ballistic and navigational support of GNSS spacecraft missions is given as an example of usage of the proposed technology. As a result, the component parts of the complex containing probable errors that disturb normal functioning were detected. Moreover, the methods for their elimination are defined. Conclusions are drawn about the practicability of using a systematic approach in the form of the proposed technological scheme for the analysis of work of the hardware and software objects for data processing in the space industry.

Keywords: system approach, issue, system, subject area

Introduction

The automated complex of programs for ballistic and navigational support (ACP BNS) of spacecraft (S) control is a difficult technical system, which functioning is connected with the usage of the following types of support during the regular work: mathematical, program, information, technical, and other types. Each type of the support is a subsystem consisting of a group of the interconnected elements. Flawless operation of all subsystem elements provides the timely and qualitative solution of complex problems.

ACP BNS operation has shown that in some cases due to various reasons there is a violation of normal work of a complex, which is expressed, as a rule, either in lack of the solution or in obtaining the solution to inadmissible accuracy. The operational analysis of such situations being made gives a chance to establish only the fact of existence of a problem, but not the reasons of its origin.

The article gives a generalized technology of the solution of problematic issues of such kind. The description of an example of using the technology for identification of the possible reasons of abnormal work of ACP BNS is given and methods of their elimination are offered. It is supposed that the procedure of using the generalized technology for solving such situations has an iterative character.

1. The generalized technology for the problems solution

The basic concepts used in this article should be defined: a system approach, problem, system and subject area necessary for logical justification of the offered technology for the solution of problematic issues [1-3].

A system approach in work is the approach to research of an object (a problem, phenomenon, and process) as to the system where elements, internal and external relations are allocated, which influence in the most substantial way the results of its functioning being studied, and the purposes of each of elements are defined from the general mission of the object. In turn, a hierarchically ordered set of questions characterizing a difference between the valid and desirable condition of the object is understood under a problem.

According to the classification by the structure degree, all problems are subdivided into three classes:

- *well-structured,* or quantitatively expressed problems, which lend itself to mathematical formalization and are solved using formal methods;
- *unstructured,* or qualitatively expressed problems, which are described only at the substantial level and are solved by means of informal procedures;
- *semi-structured,* or mixed problems, which contain both qualitative elements and the little-known, uncertain parties, which tend to dominate.

Further, a subject area is a part of the real world considered within this context. The context is an area of research, which is considered an object of some activity.

A system (from ancient Greek σύστημα – a whole made of parts; combination) is a set of interacting or interdependent component parts forming a complex/intricate whole, which quantities surpass the qualities of the forming parts.

At this time a problem solution is discrepancy elimination between a desirable and valid condition of the object. In further reasoning a concept “problems” will be used in relation to an assessment of system functioning of a certain subject area (SA).

It should be noted that a system (as well as a problem) has a hierarchical structure uniting in the whole certain quantity of the interconnected parts. Therefore, the solution for any functioning system can consist (generally) in elimination of the revealed discrepancy of work of one or several parts, which are at one or different levels of a system hierarchy.

In case of finding the solution not for all parts of the system defined as “infected”, it is necessary to make an assessment of a solution degree.

As the generalized technology of a solution for some system, it is possible to consider the following step-by-step sequence of solution stages.

1st step. System decomposition into the largest functionally completed fragments of the first level.

2nd step. Carrying out the analysis of possible discrepancy to normal functioning of the selected fragments (identification of the “infected” parts of the system).

3d step. Problem formulation for the “infected” parts.

4th step. Definition of a structure degree of operation problems of the “infected” parts.

5th step. The choice of a solution method for each “infected” system part (a private problem).

6th step. Finding a private problems solution for the “infected” parts of a system.

7th step. Decomposition of the rest parts with unsolved functioning problems into the elements of the following hierarchy system level (less large) and carrying out actions on steps 1-6.

Decomposition comes to an end in two cases:

- further system decomposition of a functional sign is impossible;
- solutions of private problems for all parts of the last level are found.

8th step. An assessment of a problem solution of system functioning on a cumulative number of the solved private problems at the levels of hierarchical decomposition.

The main methods of the system analysis used when solving problematic issues

The list of the main methods of the system analysis used for the solution of the considered problems [1-3] is given in Table 1.

Table 1. A list of the main methods of a system analysis

Method name	Integrated characteristic
Analytical methods Statistical methods Set-theoretical methods Linguistic methods Semiotic methods Graphic methods	**Formal methods** – methods of the formalized representation of systems
Morphological approach Structurization methods: relevance (objectives) tree, predication graph, etc. Delphi methods Methods of expert estimates Methods of “scenarios” Methods of brainstorming (attack)	**Heuristic methods** – methods directed to activation of using intuition and experience of experts

In most cases formal methods are applied to the solution of the structured problems; heuristic methods are applied to semi-structured and unstructured problems.

Analytical and statistical methods are mostly used out of formal methods; a method of expert evaluations including expert systems, morphological approach and a method of brainstorming are mostly used out of heuristic methods.

The recommendations on the sequence of solution stages depending on the extent of its structurization are provided.

Structured problems

1) Formulation of the purpose.

2) Creation of a mathematical model for the system description in the form of a set of elements connected with each other by certain relations.

3) The analysis of the model regarding search for the “infected” parts, choice of a decision method.

4) An assessment of a solution.

Unstructured problems

1) Formulation of the purpose.

2) The system analysis regarding search for the “infected” parts; a choice of a decision method.

3) Formation of a group of experts and using a brainstorming method.

4) Using a method of expert evaluations, including development of an expert system (taking into account the results of item 3).

5) An assessment of a solution.

Semi-structured problems

1) Formulation of the purpose.

2) Formation of achievement alternatives of the purpose; an assessment of these alternatives by means of the corresponding criteria and a choice of the preferable alternative.

3) The system analysis regarding search for the “infected” parts; a choice of decision methods (formal or heuristic) depending on their structure degree.

4) Searching for a solution of private problems.

5) An assessment of the solution of a common system problem (taking into account the results of item 4).

The following figure gives a technological search scheme for problem solution in the form of a block diagram of a step-by-step technology.

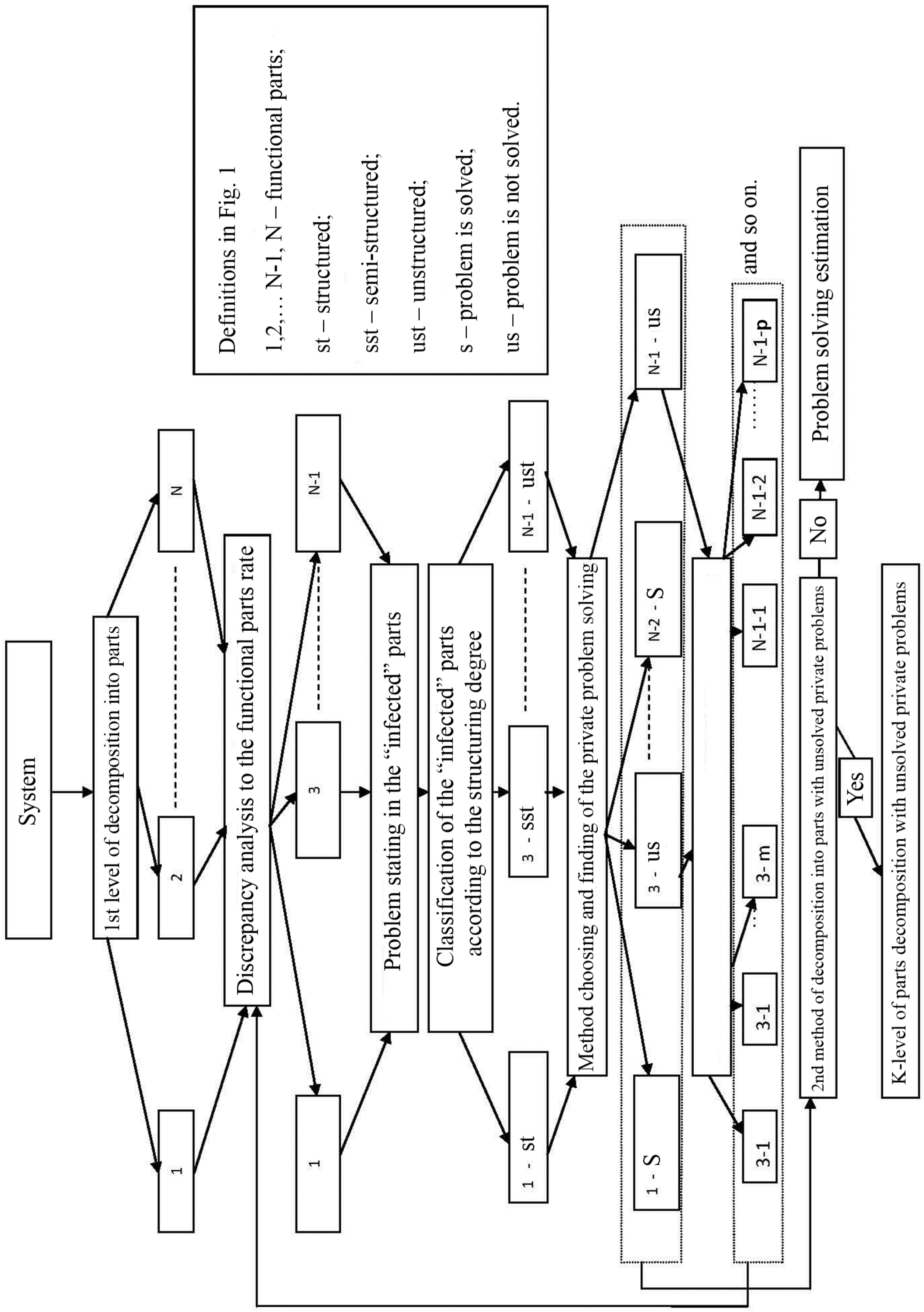

Figure 1. A technological scheme for problem solving

2. Using the generalized technology for searching the ACP BNS operation

As an example, it is possible to consider the problem of unsatisfactory work of ACP BNS, which is expressed in an inadmissible deviation of the current navigation parameters of characteristics of the spacecraft movement calculated on measurements from reference values (the final data provided in the GNSS spacecraft catalogs).

A subject area, which the object of research belongs to, should be specified. In this case it will consist of the following main support types: mathematical (algorithmic), program, technical and information. These support types can serve as functional parts of the first decomposition level.

The analysis of possible discrepancy to normal functioning of the allocated parts has shown that as far as the solution has been found, all support types functioned. However, if the problem was in failure of the technical support (lack of power supply on a server input, mechanical damage of its details, etc.), then it would result in lack of the solution. Nevertheless, as the solution took place, the technical part can be excluded from further consideration. Thus, it is possible to consider algorithmic, program, and information parts to be the "infected" parts.

At the same time, the formulation of a problem remains the same – the unsatisfactory accuracy of the received solution.

All three remaining parts containing possible mistakes (problems) leading to the current situation have in general a structured (an algorithmic part by definition) and semi-structured (program and information parts) character.

Probable existence of a problem in the algorithmic part results in need of its further decomposition into components, namely, into a module of preliminary processing of trajectory measurements (PP) and a determination module of spacecraft movement parameters (a solution of a boundary problem – BP).

The output data of PP is a session measurements table (trajectory measurements of one spacecraft for one tracking station on the set time interval). The number of sessions will be defined by multiplication of at the same time measured types of parameters by the number of measuring points. At the stage of PP the filtration (including rejection) measurements of the current navigation parameters by the set criteria is made. At this, the percent of the defective data has to make a certain part from all measurements accepted in processing and providing convergence of a problem solution. At non-performance of this condition of the measuring information obtained by BP for further calculations will be insufficiently that can lead to inadmissible mistakes in the specified movement of the spacecraft parameters.

Thus, one of the reasons of the existing problem can be in lack of a condition of a necessary minimum of a number the sessions and numbers of measurements in a session, which existence substantially would explain the unsatisfactory solution of a problem.

The module of the solution of a BP is mathematically much more difficult than the PP module. It includes: a model of the spacecraft movement, matrix private derivative of measurements on entry conditions, statistical processing methods of measurements (for example, a method of the ordinary least squares (OLS), methods of integration of the differential equations of the movement, formation and the decision of systems of a large number of the linear equations, interpolation and approximating polynomial, etc. Traditional conditions of the solution of similar problems are well approved and, as a rule, do not cause difficulties. At the same time, as the weakest spot at the solution of a BP it is possible to consider an opportunity of bad conditionality of the matrixes used at the solution of the normal equations for calculation of amendments to parameters of an orbit and to other specified parameters. For OLS it is Gram matrix. An expedient solution of this problem is introduction at this stage of calculations of the criterion of the degree of conditionality of matrixes.

The problem in the information part can be formulated in two variants:

- lack of the whole necessary information or a part of it;

- presence of mistakes in the obtained information for this processing session.

To find the reasons of the problem arising, it is necessary to decompose the information part into the following hierarchy level, namely, information sources: the central data base (CDB) and internal FTP-server of the augmentation and monitoring system (SAM). As the essence of a problem concerns directly information, it is necessary to move to the following level – an information level – distribution of information on sources (Table 2).

Table 2.Sources of the data being used

Source of information	Type of information
CDB	Navigation messages: real-time data, almanac; Reference data: logical power scale, global constants, technical characteristics of signals, parameters of exciting force (for example, charged-coupled device (CCB), spacecraft.
Internal FTP-server	Rinex-files

Probability of existence of mistakes in information, which is contained in sources, should be analyzed. Thus, for CDB:

- navigation messages (real-time data and almanac) are in a supershot, which is transmitted from the spacecraft to ground stations each 2.5 min. At receiving check on reliability is automatically made. These data are used by all the Centers – the participants of GNSS. At the same time mistakes are improbable;

- reference data are registered in the base once, are carefully checked, used at each session of the GNSS spacecraft orbits definition that makes it possible to consider (by the analogy with navigation messages) improbable existence of errors in them;

- parameters of the Earth rotation – the data on the CCD "read" from the external special server that are in the form of the annual massifs containing the daily information (t, x_p, y_p – time and coordinates of poles) used by all participants of GNSS. Mistakes are almost excluded.

Rinex-files of the set type. Their contents include:

1. File of observation data (FOD): time, pseudo-range, phase, and Doppler correction.
2. File of navigation messages (FNM).
3. File of meteorological data (FMD).
4. File of GLONASS navigation messages.
5. File of GEO navigation messages.
6. File of data satellite clocks and receivers (FDW).
7. File of wide area updating information SBAS (FWUI).

From the submitted files, FOD files should be considered, which data are used in a session of information processing and may contain errors. At this FOD includes: time, pseudo-range, phase, and Doppler amendments.

Three variants of existence of private problems are possible:

1. Lack of information on any of parameters.
2. Existence of low-quality data.
3. Presence of an incomplete volume of data.

In the first variant it is possible to allow lack of Doppler measurements; in this case there will be no "a solution on speeds", but the solution of a problem will be received. Lack of information on time or pseudo-range, and also data on a phase causes impossibility to determine the specified orbit parameters on any of spacecraft.

In the second variant it is necessary to separate low-quality information from qualitative. The main criterion of such division is the place corner γ, under which there was a reception of a signal from the spacecraft in a visibility range of the measurement station (MS). It has experimentally been established that at $\gamma \leq 70$ the information obtained by MS is of low quality (a big noise level due to the atmosphere). Observance of this condition when loading information into the base at the first stage of PP will enable one to remove the low-quality information prior to calculations and to provide necessary accuracy.

In the third variant the incomplete volume of information is caused either by passing of the route across the "edges" of visibility ranges of MS or removal of part of information on a condition $\gamma \leq 70$. The most radical solution of this problem is removal of this spacecraft from the processing variant.

The software, as well as algorithmic, is expedient to divide into two main programs of a complex: preliminary processing of measurements and determination of parameters of an orbit (a following level).

Private problems of programs are formulated as follows: PP – formation and recording into the archive an insufficient amount of qualitative sessions of measurements on each spacecraft; BP – determination of parameters of spacecraft orbits with an unsatisfactory accuracy.

It should be accepted that the algorithms of PP and BP transformed into the codes of programs are identical and have no errors. Considering that programs are a set of interdependent modules where both analytical calculations and different information transforms are made, it is necessary to continue the "decomposition" of the software (S) of ACP into software modules. The first level for the software: general modules of the automated complex of programs (ACP), PP, and BP. The decomposition of the software parts at the following bottom level should be continued.

The general modules of ACP:

- settings of operation modes and configuration of a complex (formation of setting files);
- software modules of interaction with the database (DB);
- software modules of interaction with file archives.

Preliminary processing of measuring information (PP):

- formation of measurement sessions of the current navigation parameters (MCNP);
- processing and filtration of sessions MCNP;
- formation of sets of basic lines;
- formation of differential measurements;
- filtration of sessions of differential measurements;
- determination of location (DL) on code measurements of the range;
- statistical assessment of results of DL.

Expeditious specification of orbits parameters of navigation spacecraft (BP):

- solving a boundary problem (BP);
- specification of clock error predictions (CEP).
- formation of the archive of the corresponding files.

Practice of the ACP software operation has shown that one of the main problems in determination of orbits parameters of navigation spacecraft is identification of "jumps" of the phase measurements (processing and filtration of measurement sessions in PP) reflecting violation of reception and loss of the account of an integer of phase cycles in the phase measurement device.

In PP a check of phase measurements by means of the methods based on use of combinations of Melbourne-Vubben and Geometry-Free [2] is realized. However, the specified methods do not solve until the end a problem of "jumps" and in case of hit of such measurements to the BP module lead to solutions with an unsatisfactory accuracy. A way out is development of the expert and diagnostic system (EDS) for a specific case. Now the EDS prototype is developed for an assessment of the location module (PP module) [4-6] that can serve as a technological sample for development of EDS – "jumps".

In other modules the random errors made when writing programs are possible. Their identification is made at a stage of testing of a complex as the compulsory procedure, which is carried out before using ACP in practice.

Conclusion

The considered approach to the solution of problems of failures in work of ACP BNS permits drawing the following conclusions.

1. For the analysis and the solution of the problems arising during the work of ACP BNS, it is recommended to consider a complex as a system with a hierarchical structure.
2. The generalized technology for the problems solution of work of functionally difficult systems in the form of eight stages, which basic elements are the components received by decomposition of the system on a functional sign, is offered. The degree of their structure is defined and the solution of private problems for the "infected" parts using the methods of the system analysis is proposed.
3. Possible options of problems in work of ACP BNS are considered, the complex components containing probable mistakes in the "infected" modules are specified and methods of their correction are offered.
4. The offered technological diagram for the problems solution within the systems concept can find application in case of evaluation of the work of hardware-software systems of the space branch.

References

1. Tarasenko F.P. *Prikladnoy sistemnyy analiz* [An applied system analysis]. Manual. Tomsk, Izdatel'stvo Tomskogo universiteta, 2004. (in Russian)

2. Genike A.A., Pobedinskiy G.G. *Global'nye sputnikovye sistemy, opredelenie mestopolozheniya i ikh primenenie v geodezii* [Global satellite systems, positioning and their application in geodesy]. Moscow, Kartgeotsentr, 2004. (in Russian)

3. Metodika sistemnogo analiza [A system analysis method]. Paper. Mht. 2014. (in Russian)

4. Betanov V.V., Larin V.K., Pozyaeva Z.A. Baza znaniy dlya programmnogo modulya opredeleniya

mestopolozheniya priemnika [A knowledge base for a program module for receiver location detecting]. *Sb. statey No. 6 "ITMiVT im. S.A. Lebedeva RAN"* [Proceedings No. 6 of JSC "IPMCE"], 2015. (in Russian)

5. Betanov V.V., Larin V.K., Pozyaeva Z.A. K voprosu analiza prichin vozniknoveniya sboev v apparatno-programmnom komplekse utochneniya effemeridno-vremennoy informatsii GNSS [The analysis of error occurrence causes in the GNSS hardware-software complex of ephemeris and time data refinement]. *Nauchno-technicheskiy zhurnal "Raketno-kosmicheskoe priborostroenie i informatsionnye sistemy"* [Scientific and technical journal "Rocket-space device engineering and information systems"]. 2014, Vol. 1, No. 1, pp. 55–60. (in Russian)

6. Betanov V.V., Larin V.K., Pozyaeva Z.A. Prototip ekspertnoy diagnosticheskoy sistemy poiska i korrektsii skachkov v bezraznostnykh fazovykh izmereniyakh [A prototype of the diagnostic expert system for search and correction of surges in non-difference phase measurements]. *Nauchno-technicheskiy zhurnal "Raketno-kosmicheskoe priborostroenie i informatsionnye sistemy"* [Scientific and technical journal "Rocket-space device engineering and information systems"]. 2014, Vol. 1, No. 3, pp. 73–81. (in Russian)