Problematic Points regarding Autonomous Functional Control of Low-orbit Remote Sensing Satellites

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Abstract: The report herein tackles crusial issues of remote sensing satellites motion control and ballistic and navigational support. There are demonstrated ways of extending unmanned satellites survivance in contingencies. There are investigated approaches to definition of satellite autonomy criteria, as well as problems of in-flight tasking of onboard hardware.

Keywords: satellite, control, autonomy, survivance, remote sensing, in-flight coordinates tasking, ballistics, navigation

1. INTRODUCTION

Maintaining autonomy of an unmanned satellite is of paramount importance on all phases of its life-cycle, and, first of all, it is linked to intellectualization of control procedures (Akhmetov, 2006; Akhmetov et al., 2006). Thereupon consideration of the following issues is of high interest as regards remote sensing satellites:

- satellite autonomous attitude control;
- autonomous resolving of ballistical and navigating tasks
- in-flight coordinates tasking
- improvement of satellite survivability
- development of signature remote sensing
- development of criteria for estimation of autonomy of a remote sensing satellite

2. SATELLITE AUTONOMOUS ATTITUDE CONTROL

Type of a remote sensing satellite control procedure is in many respects determined by the selected control method of aiming the imaging equipment optical axis on observable objects.

Historically, the first method of aiming the imaging equipment line-of-sight at a target was software-based temporal method when the satellite work program was shaped in the ground mission control center and time of imaging equipment actuation as well as duration of its operation were transmitted aboard by radio channel. Attitude control of modern remote sensing satellites is performed by coordinate – temporal method which on the one hand, allows uplinking of swath coordinates, and on the other hand, autonomous creation of an attitude control program for imaging aboard the satellite. There may be set a great variety of swaths within a certain coverage area (Akhmetov, 2008; Kirilin and Akhmetov, 2007). Each of swaths is characterised by initial geodesic co-ordinates (φ_0, λ_0), scanning azimuth (A - relatively flight track or A – relatively meridian of the swath initial point), swath length (τ). All data necessary for autonomous synthesis of the attitude control program aboard satellite are also determined and calculated independantly, i.e. without support from the Earth. These data include:

- Motion parametres (co-ordinates, velocities) of the satellite mass center (MC) in the Greenwich co-ordinate system (atonomous navigation task), time;
- Satellite angular position and angular velocities in the inertial system of co-ordinates (attitude and orbit control system);
- Distances from the Spacecraft MC to a point on the Earth surface to be imaged;
- Prediction of the Spacecraft MC motion and attitude for the moments of imaging.

Generally, while compling an atttitude control program it is necessary to satisfy following conditions and limitations:

- Velocity of the longitudinal imagery motion in the imaging equipment focal plane should satisfy the following conditions:
  - Along the central line-of-sight

$$(W_{xp}/D) = (W_{xp}/D)_g = const\,, \qquad W_{zp}/D = 0.$$

  - At the left and right edges of cental line on focal plane' frame the values (W_{xp}/D) are equivalent.

Here $(W_{xp}/D)_g$ - parametre defining velocity of the imagery longitudinal motion in the receiving device, W_{zp}/D - velocity of the imagery crosswise motion, D – distance from the satellite MC a spoint on the Earth surface to be imaged.

- Boundrary conditions for maximum allowable modulo angular velocity and angular acceleration

$$|\boldsymbol{\omega}(t)| \le \omega_g = const, \qquad |\boldsymbol{\varepsilon}(t)| \le \varepsilon_g = const.$$

Note, that Satellite attitude control program shall take into account piculiarities of control both on swaths and on inter-swath gaps. To provide effective control on

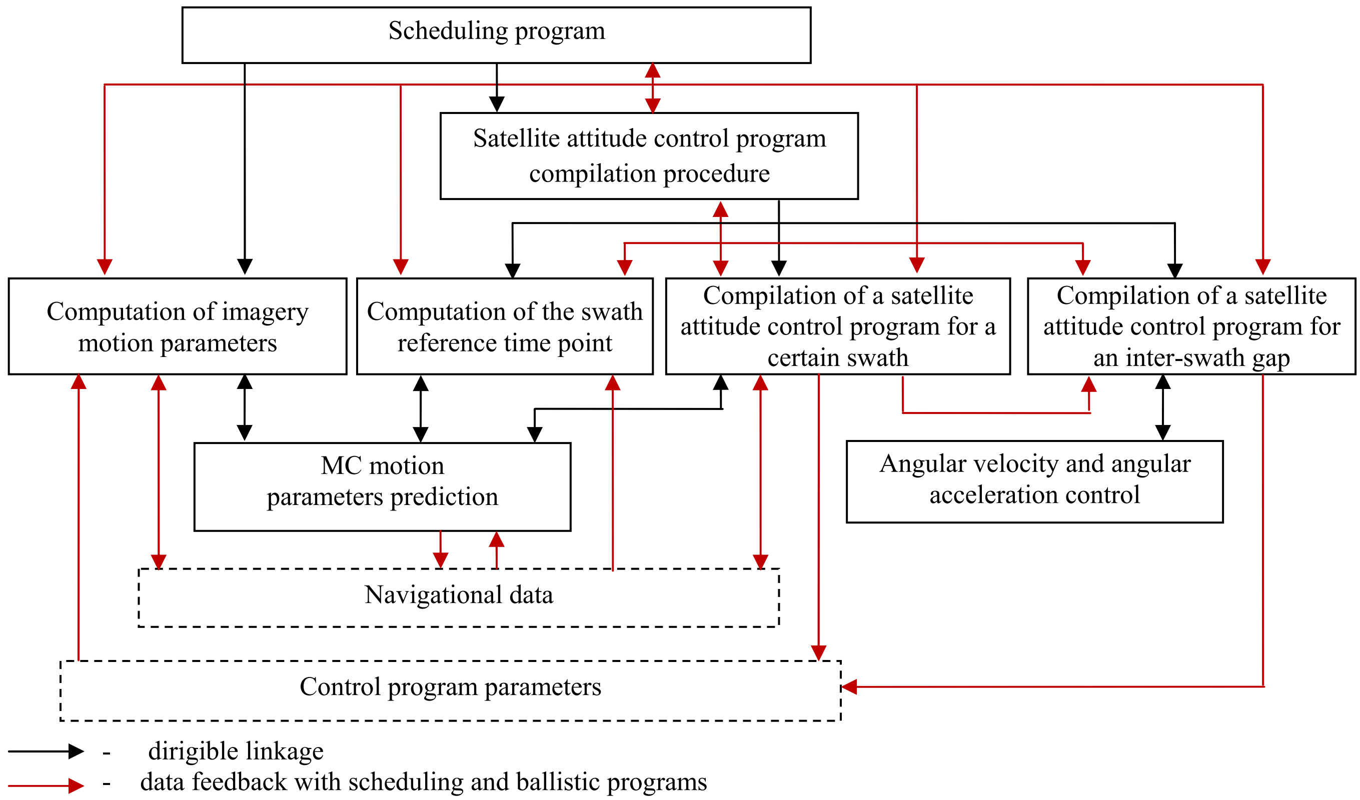


Fig. 1. Block diagram for creation of a remote sensing satellite attitude control program

inter-swath gaps it is advisable to minimise satellite slew time and also time needed to meet the second of the above mentioned limitations. Spacecraft attitude control program block diagram for Resurs-DK Spacecraft is given in Fig.1

Satellite position control and stabilising relatively MC is done in an orbital co-ordinate system with respective turning all the three satellite body axes relatively the orbital axes. Modern remote sensing satellites make use of electrostatic booster guidance, meaning that all calculations are executed in an absolute inertial system of co-ordinates (Akhmetov, 2008; Kirilin and Akhmetov, 2007; Landau et al., 2008).

The logic of target acquisition and tracking depends on the adopted method of imaging. There are recognized: target detailed imaging, strip imaging, ground area imaging, stereoscopic imaging and random-azimuth imaging. Examples of various kinds of imaging performed by Resurs-DK1 Spacecraft are given in Figs. 2, 3. Note, that aiming of the imaging equipment axis-of-sight on the swath central line, and guaranteeing the required velocity of sighting in the longitudinal direction is done with programmed pitch and roll; guaranteeing minimum velocity of optical image crosswise motion in focal plane is done with a programmed yaw turn (Akhmetov, 2008; Kirilin and Akhmetov, 2007).

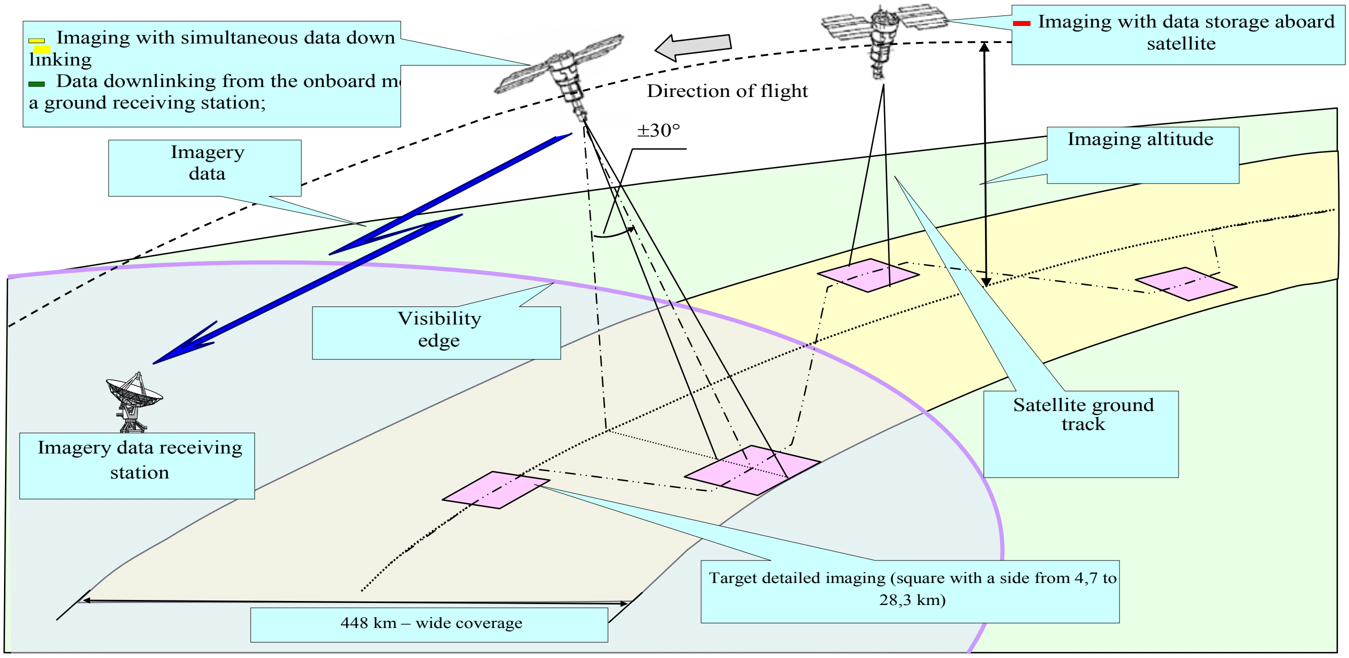
For autonomous synthesis of the attitude control program it is necessary to know and to predict Spacecraft MC motion parametres, results of imagery motion parametric analysis, that is linked to resolving of ballistic and navigational tasks

3. AUTONOMOUS RESOLVING OF BALLISTICAL AND NAVIGATING TASKS

Analysis of the Spacecraft in-flight control shows, that generally ballistic and navigational information is necessary for the Satelltie gridding and time referencing in a rapid and effective way in the course of its orbitital flight. It is done by integration of GLONASS and GPS sensors in the Spacecraft control circuit thus creating an onboard navigation satellite system for efficient execution of the following tasks:

- navigational computations basing on global navigating satellite system signals and direct navigational definitions of the satellite MC motion parameters;
- refinement of the satellite MC motion parameters by results of statistical processing of direct navigational definitions of the satellite MC motion parameters;
- updating of the satellite MC motion parameters for users of the onboard control system;
- creation and accumulation of navigating and housekeeping information for downlinking to the ground mission control center.

Resurs-DK1 onboard navigational system consists of software installed in the onboard control system computer system, and measuring hardware - onboard time-coordinate synchronizer.



- Imaging with data storage in the onboard memory device;
- Imaging with data storage and its simultaneous near real-time downlinking to a Receiving Station in the direct visibility area;
- Data downlinking from the onboard memory to a ground receiving station;

Fig. 2. The Resurs-DK1 imaging capabilities

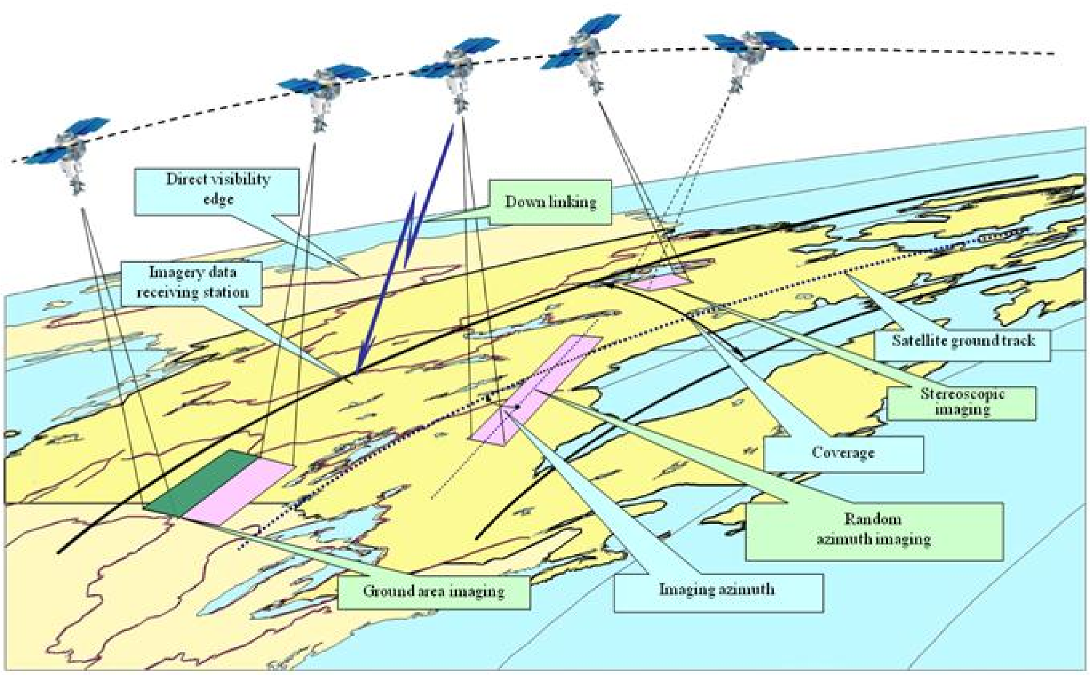
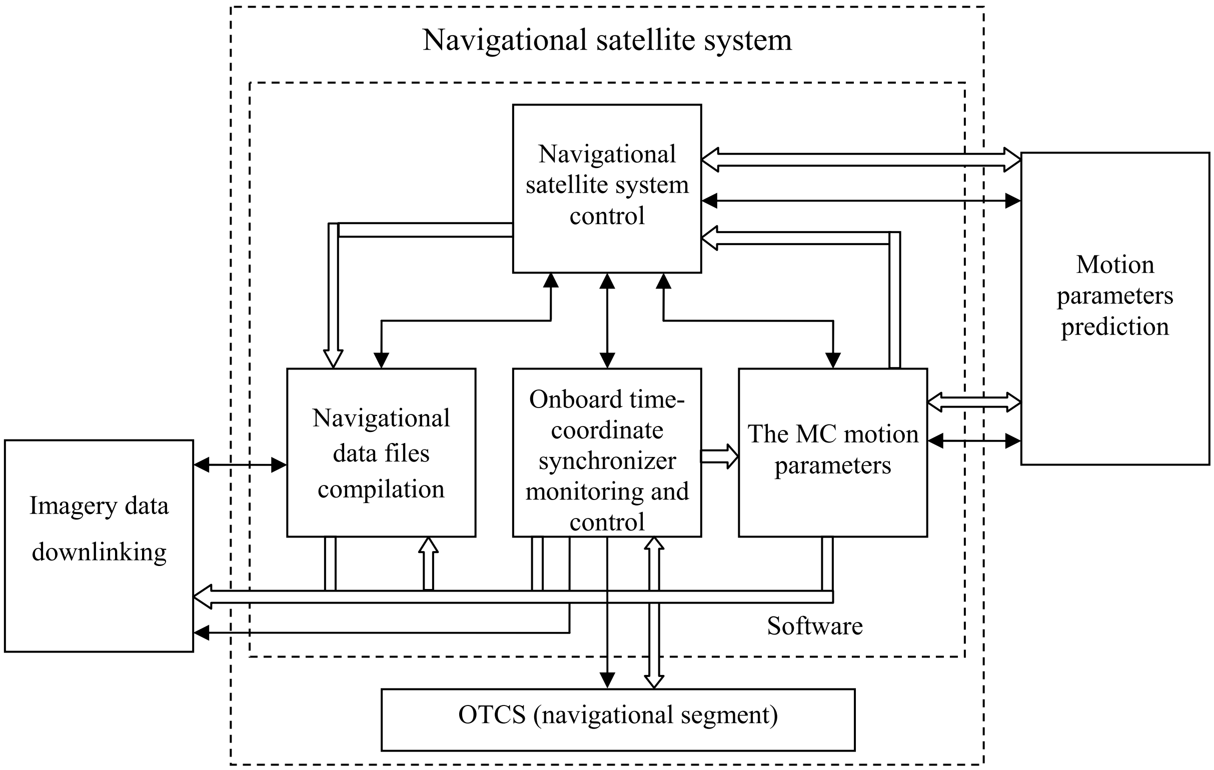


Fig. 3. Stereoscopic and Random-azimuth imaging.



OTCS - onboard time-coordinate synchronizer;

- dirigible linkage;
- data feedback.

Fig. 4. Block diagram of the onboard navigational satellite system

Block diagram of the onboard navigational satellite system is given in Fig. 4. In this Fig. structure of the navigation software is highlighted by a dotted line. Navigating data are shaped by means of Satellite motion parametres prediction using its motion model and environment model.

Motion parameters are updated in the onboard control system by results of onboard navigational satellite system activity periodically with interval $\Delta\tau$ in order to keep their required accuracy.

Every day of flight the onboard navigational satellite system compiles several files with motion parameters for given times. These files are incorporated in data to be downloaded to the ground mission control center. Minimum and maximum time for statistical processing of direct navigational definition outcomes and, correspondingly, periodicity of motion parametres update in the onboard control system is determined pursuant to:

- necessity to urgently schedule and coordinate satellite control within a time interval, comparable with one orbit;
- reaching the required accuracy of motion parameters by the beginning of time period alloted for fulfillment of a certain functional task;
- possibility to have navigational definition sessions taking into account discontinuity of the GLONASS navigating field operating simultaneously with the Spacecraft orbital flight.

Over three years navigational satellite system built by the indicated principles has successfully supported fulfillment of imaging tasks and continuous autonomous operation of Resurs-DK1 (Akhmetov, 2008).

To increase autonomy and survivance of the satellite it is necessary to guarantee fulfillment of navigational tasks in conditions of non-completely deployed GLONASS system and possible local malfunctions of GPS system.

Besides, usage of radio navigational fields of these systems does not contribute to high-precision positioning of a space craft. Therefore, more challenging is creation of integrated inertial - satellite systems able to cope with navigational and positioning tasks.

This may be feasible in case of multipurpose utilization of measuring information received from inertial sensors, star trackers and global navigational satellite system. Inertial sensors and star trackers are the basic sensing elements of modern Spacecraft motion control systems.

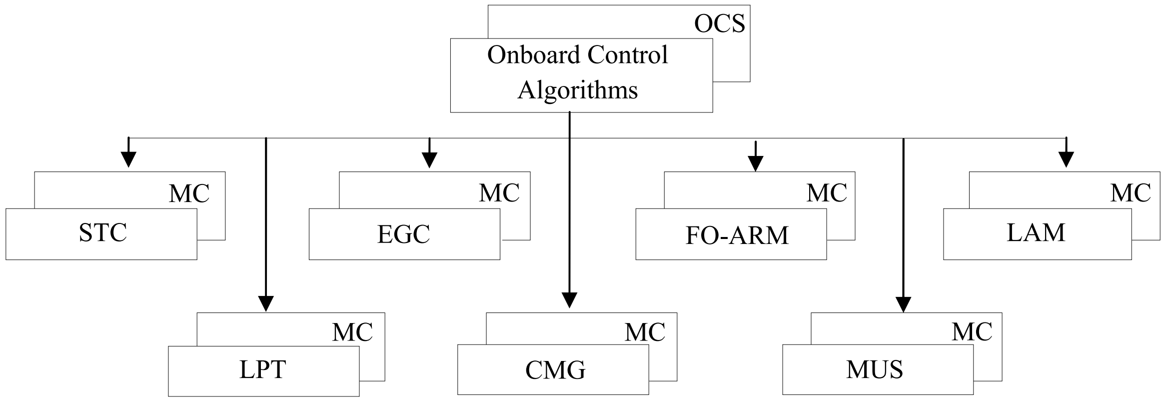


Fig. 5 Block diagram of Resurs-DK1 attitude control system: OCS - onboard computer system; MC – microcontroller; STC – Star Tracker Cluster; EGC – electrostatic gyro cluster; FO-ARM - fiber-optical angular rate meter; LAM - linear acceleration metre; LPT - liquid-propellant thruster; CMG – Control Moment Gyro; MUS –magnetic unload system .

4. PICULIARITIES OF IN-FLIGHT COORDINATES TASKING FOR THE ONBOARD HARDWARE OF A REMOTE SENSING SPACECRAFT

4.1. Essence of the in-flight tasking

At the present stage of remote sensing satellites development there has appeared an contradiction between attained pinpoint accuracies provided by the onboard hardware (seconds of arc) and mutual misalignment of their sensitivity axes when operating as a part of a satellite, attaining several minutes of arc that results in reduction of the satellite orientation accuracy and aggravates quality of the target information.

It is not obviously possible to eliminate such a contradiction barely by certification of the onboard hardware in ground environment. The effective approach to this problem consists in conducting of geometrical coordinates tasking for the onboard hardware (including imaging equipment) directly during satellite orbital flight (Egorov et al., 1991; Somov et al., 2008).
We consider in-flight coordinates tasking for the onboard hardware as a verification process performed aboard satellite aimed at detection and estimation of onboard hardware intrinsic errors including installation errors of imaging equipment and onboard segment of the attitude control system, their mutual alignment and certification, with the subsequent consideration of these ambiguities while controlling satellite attitude in real time.

Our enterprise has been studying scientific and applied aspects of in-flight tasking of satellite onboard hardware since the 80-s of the last century, in order to reduce deviations of the satellite strapdown attitude control system based on standard measuring instruments (sensors) of its angular velocity. There were developed tasking procedures for other gyroscopic measuring devices using sensors acquiring external information, in particular, dynamic star trackers (Dumin et al., 2005a, b; Landau et al., 2008). In modern remote sensing satellites hardware-algorithmic structure of the attitude control system has undergone considerable changes that have demanded new approaches to the in-flight tasking. One of attitude control system versions implemented on a remote sensing satellite of Resurs-DK1 type is given in Fig. 5.

Each of these systems possesses its own calculator (microcontroller) which, along with unitization of data communication channels with central computer system unit and fulfillment of onboard hardware mission functional tasks, stores and registres data on basic parameters data certification and verification.

4.2. In-flight tasking research guidelines

Due to constant toughening quality requirements on imagery data received by modern remote sensing satellites, increased attention is paid to tasking of the onboard equipment. Research guidelines in this sphere are the following:

- Tasking of attitude control system instruments (namely, EBG, .SLSST, FOARM gyroscopic and star trackers) directly by developers under conditions of the Earth on special-purpose test-benches;
- Definition of the satellite configuration and implementation of corresponding design and technological procedures aimed at correct tasking (eg., placing of attitude control system sensitive elements on a common platform - thermostabilized plate, imaging equipment base frame, mutual alignment of the instruments' base axes and etc.);
- Tasking of the onboard hardware during orbital flight performing special tasking procedures and specification of models and algorithms hardwired in the instruments' processors;
- Working out of special angular maneuvers for satellite tasking and estimation of different by nature errors of attitude control system and imaging equipment;
- Development of special onboard systems and working

out of certain tasking modes that allow combined operation of the attitude control system and imaging hardware;

- Development of algorithmic support for in-flight tasking procedures creating virtual attitude control system devices (i.e. their algorithmic models);
- Working out of in-flight calibration techniques implementing regular angular maneuvers performed by satellite in the process of its functioning.

Landau et al. (2008) present techniques and results of EBG in-flight geometrical coordinates tasking performed during Resurs-DK1 flight qualification test. Such tasking is carried out by stellar monitoring and taking into account a corresponding deviation mathematical model (DMM) adapted for conditions of orbital flight, developed at EBG design stage. DMM coefficients were defined at EBG development tests. DMM and corresponding coefficients are stored in memory of the EBG central computer and underlie the calculation algorithm of gyro deviation during orbital flight. Peculiarity of this procedure is the following: during tasking and reference orbits satellite angular position is simultaneously measured by EBG and STC, the obtained data id downlinked via telemetry to a Ground Mission Control Center and after processing are uplinked to be used during satellite real-time attitude control.

At stellar monitoring and adjustment of EBG gyros measuring axes position, there are used data obtained from external orientation sensors (that is from onboard STC star coordinators) as reference values of satellite angular position (Anshakov et al., 2008; Dumin et al., 2005b). However, accuracy of EBG measuring axes positions relatively inertial coordinate system are different: accuracy of optical axis positioning (direction perpendicular the sensor placement location) 10 times surpasses accuracy of other two axes positioning. Required accuracy of satellite attitude position may be reached if there is used information from two synchronously operating STC, mounted aboard satellite under different angles. But period of time when synchronous operation of two sensors it is possible, is limited as well (due to the Sun, the Moon, the Earth overexposure).

Research work by Anshakov et al. (2008) deals with tasking of the outer orientation sensors, STC in particular, in a novel way using generation and implementation of a "virtual" device, in other words STC mathematical model. It guarantees accuracy of the Satellite attitude position definition comparative to accuracy demonstrated by the technique with two synchronously operating STC. In this case, having defined discrepancies in readings of the real and "virtual" STC, it is possible to control satellite by measurements of only one SLSST. Note that number of periods when it is possible to have two STC synchronously operating is considerably below the number of periods when one STC may operate. Such approach allows to consider errors of STC sensitivity axes set-up relatively Satellite axes and start quasi-continuous control of the satellite based on STC measurements.

Mathematical aspects of the in-flight geometrical coordinates tasking based on data of combined activity of space telescope and star tracker system are considered in the research work by Somov et al. (2008). Analyzing heritage of Resurs-DK1 it is possible to conclude the following:

- It is necessary to provide an automatic onboard tasking of EBG without on-ground processing of telemetry data, that will essentially raise efficiency of tasking and will increase productivity of the satellite;
- At designing of new satellites and in order to reduce offset of EBG and STC measuring axes it is expedient to provide possibility of installation of these sensors on a common platform.

4.3. Peculiarities of in-flight calibration

The essence of geometrical coordinates tasking for the onboard hardware of attitude control system and imaging equipment mounted on a uniform platform (main frame or thermostabilized plate) consists in the following. SLSST directly determines satellite position (or SLSST instrument axes) relatively inertial coordinate system. By means of FOARM (or EBG) there is determined satellite position on intervals between stellar monitoring by satellite angular velocity measured relatively FOARM sensitivity axes (by integration of the known satellite motion equations at the initial angular position measured by SLSST) (Somov et al., 2008).

In the case under concern two modes are analyzed. These are: the so called stellar monitoring and matching of star tracker imaging equipment axes mode (AKSO) when position of their measuring axes is determined by stars. And there is a mode for platform / imaging equipment main axes current position is controlled by means of autocollimation measuring system and matching of axes (ASSO). The AKSO technique incorporates two phases. The *first phase* is implemented directly during satellite flight and includes imaging of celestial map simultaneously by star trackers and imaging equipment, i.e. an optronic telescope system. The *second phase* implies combined on-Earth processing of celestial imagery data acquired by star trackers and optronic telescope. Here are as well taken into account data received by ASSO technique. The ASSO technique guarantees matching of the attitude control system onboard hardware platform and optronic telescope optical axes with an error of 3 seconds of arc.

However the interval of time from the moment of reception (measurement) of data up to their application turns to be considerable, that leads to unsuspected mismatch of the onboard equipment axes.

On completion of AKSO mode there became known orientation of optronic telespope base line and star trackers base line for a certain instant of time relative to inertial base line I. By results of ASSO mode there is determined orientation of the platform (P) relatively optronic telescope base line. By results of AKSO mode there is computed current relative position of the optronic telescope and star trackers base lines (quaternion Λ_{OT}^{A}):

$$\Lambda_I^A = \Lambda_I^{OT} \circ \Lambda_{OT}^A \qquad \text{or} \qquad \Lambda_{OT}^A = \widetilde{\Lambda}_I^{OT} \circ \Lambda_I^A$$

Quaternion Λ_{OT}^{P} defined by ASSO at the moment of active AKSO mode, and corresponding quaternion Λ_{OT}^{A}, defined by star trackers, will vary in the course of nominal operation because of satellite frame thermal deformation. Increment of quaternion Λ_{OT}^{P}, determined by ASSO allows to receive current quaternion $\Lambda_{OT}^{A}(t)$ for the time interval of optronic telescope operation:

$$\Delta\Lambda_{OT}^P(t) = \widetilde{\Lambda}_{OT}^P \circ \Lambda_{OT}^P(t)$$

$$\Lambda_{OT}^A(t) = \Lambda_{OT}^A \circ \Delta\Lambda_{OT}^P(t)$$

In Figs. 6 and 7 quaternions to be calculated are shown by dashed lines.Here are introduced the denotations:
OT – Optical telescope; ST – star tracker; P –Platform; A - Star Tracker Cluster; SLSST - unit for determination star co-ordinates including a number of motionless star trackers (star locator with static star trackers); Sat - satellite; AKSO – stellar monitoring and axes matching mode; ASSO – autocollimation measuring and matching of axes mode; SE MCS -Sensing elements of the motion control system.

Thus, attitude control system onboard equipment position relative to optronic telescope optical axes may be computed basing on data received in AKSO modes; whereas variation of the optronic telescope and star tracker current position are estimated by means of ASSO (see Figs. 6, 7). The acquired data is used in the attitude control system to control satellite position and promoting acquisition of the higher quality imagery.

5. THE SATELLITE SURVIVABILITY

The strategy of survivability improvement includes the following (Akhmetov, 2006; Akhmetov et al., 2006; Akhmetov, 2008):

- In-flight on-board monitoring of satellite functioning;
- Effective testing of satellite systems fitness;
- Compilation of an onboard database of contingencies;
- Atonomous analysis of satellite systems status in contingencies;
- Compilation of onboard correct reference points database;
- Atonomous rollback to reference points in contingencies;
- Autonomous rearrangement of controls to recover satellite functions;
- Balance of centralised /decentralised control principles;
- Implementation of standard functional patterns (modes) of the satellite onboard tools in contingencies;
- Autonomous tasking of the satellite onboard hardware.

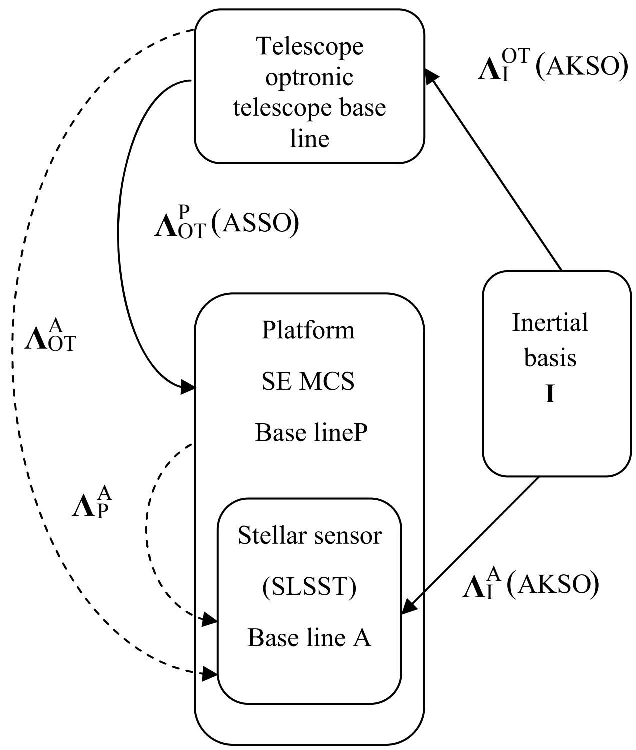


Fig.6. Definition of optronic telescope position relatively the SLSST unit

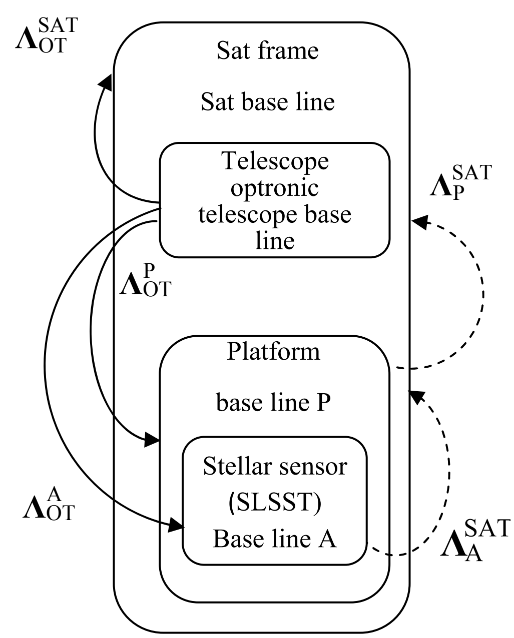


Fig. 7. Defining of the optronic telescope base line relatively FOARM (or EBG) base line

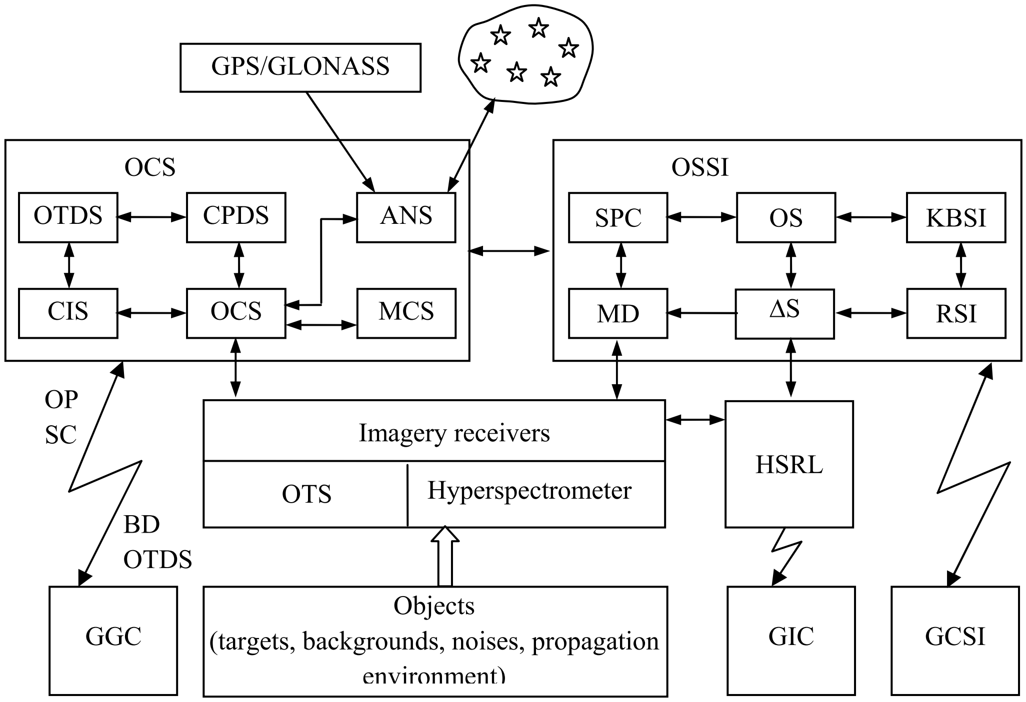


Fig. 8. Generalized block diagram of signature imaging process: OTS - optronic telescope system; OCS - onboard control system; OP - operating program; SC - single command; BD - backwards data; OTDS - onboard telemetry data system; CPDS - command relay and power distribution system; ANS - autonomous navigation system; CIS - command information system; OCS - onboard computer system; MCS - motion control system; SPC - special purpose computer; MD - memory device; HSRL - High-Speed Radio Line; OSSI - onboard systems of signature imaging; OS – onboard soft signature imaging, KBSI - knowledge base of signature imaging; RSI- Radiolink of signature imaging; CGC Flight Control Center, GCSI– ground-based center of signature imaging, GIC - ground-based imagery data processing center, ΔS – change and addition of signatures.

5. METHODS OF SIGNATURE IMAGING

Signature imaging is remote sensing with imagery data preprocessing aboard satellite before its downlinking; as a result not the complete set of imagery data is downlinked but only that part of it which demonstrates changes in the state of targets if compared to previous instant, or it may not be transmitted at all if no changes has been revealed. Such approach allows to transmit only useful information and not to stuff the downlink channel with useless data. On the other hand, such an approach demands availability of a dedicated system aboard the satellite which would allow real time determination of changes in the status of targets and other elements of the scene under observation.

In our understanding the object signature is an object characteristic (descriptor) with the help of which the object can be found out, discriminated, classified and identified. As a rule, it is not enough to have only one characteristic, therefore an object should have the whole set (tuple) of signatures. Tuple of signatures characterizing an object and used for its detection, dicrimination, classification and identification is called pattern (template).

Thus, signature imaging is obtaining of information on signatures of real targets, their comparison with the earlier accumulated and stored in the knowledge base signatures (templates) of objects, discrimination of objects, determination of changes if any, and decision making about transfer of the appropriate information to the user. The user can receive either complete information on the observable scene (objects, background conditions, obstacles), or partial information about changes (signatures, parametres), or a message on absence of changes, or no messages at all.

There are discriminated geometrical, time-space, spectral signatures, and also energetic, dynamic and fractal signatures.

Creation of onboard autonomous systems of signature imaging requires a great many technological aspects to be propelly resolved, namely:

1) Compilation of an onboard knowledge base including:

- A priori spectral characteristics of objects, backgrounds, obstacles (background – target – obstacle environment) for various spectral bands, observation conditions (flight altitude, sun aspect angle, observation angle, atmospheric status contrast), modification of the optronic system parametres recognition system parameters;
- Methods, algorithms and criteria of automatic spectral

selection of objects in various background – target – obstacle environment and observation conditions;

- Minimum necessary tuple of standard reference signatures sufficient for detection, recognition of the object class, type, size, structure, status, which on the one hand, support reqired quality performance of the onboard autonomous system of signature imaging, and on the other hand, do not complicate its design (ensuring specified probability of recognition and fitting restrictions on weight, power consumption, fabrication cost and system maintenance).

2). Software for the onboard autonomous system of signature imaging (operational environment, reduction of message redundancy and compression of imagery data, decision making on imagery data modification and transfer to the ground-based imagery data reception and processing center, interface with the satellite onboard / ground-based control system);
3). Imagery data receivers (multispectral optronic systems, hyperspectrometers), onboard special purpose computers.
4). Ground-based center of the onboard autonomous system of signature imaging optimization, testing and supporting.
5). Onboard and ground-based training systems with self-correction, self-adjustment and self-training.

Generalized diagram of the onboard autonomous system for signature imaging is given in Fig.8.

6. THE SATELLITE AUTONOMY

So far criterial estimation of a remote sensing satellite autonomy and its onboard systems have not been duly covered in scientific research. Below are discussed some approaches to determination of autonomy criteria.

6.1. Criterion of energetic autonomy

The criterion is characterized, on the one hand, by an autonomous set of devices and equipment necessary to maintain the required energy profile of the satellite: chemical power sources (nickel - cadmium, nickel - hydrogenous, lithium-ionic accumulator batteries), photovoltaic cells (silicon with 14.5 % efficiency, arsenide gallic with 26-28 % efficiency), solar arrays, power supply system, automatic voltage stabilizers, and on the other hand, onboard software which activates autonomous modes of power balance maintenance. These are: solar arrays deployment technique (two degrees of freedom), special modes of satellite turning with the purpose of energy accumulation and reaching max Cos α, maintenance of a power balance and fault recovery in power supply systems.

6.2. Criterion of functional autonomy

This is determined as relation a scope of tasks competed by the onboard control system (Fig. 9), to the total amount of tasks fulfilled by the satellite autonomous control system (onboard and ground-based control system) (Kirilin and Akhmetov, 2007). Such distribution of tasks became possible due to transfer of attitude control, satellite MC motion control, satellite control in various modes, great number of testing and diagnostic tasks aboard the satellite.

6.3. Criterion of informational autonomy

From the point of view of informational approach there should be discriminated two various circuits: imagery data circuit and satellite / orbital constellation control loop. Let’s discuss the first one.

Imagery data circuit may be considered in two aspects - in respect of creation, accumulation, compression and downlinking of imagery data; and in respect of improvement of imagery data descriptiveness (resolving capability, ground resolution). As for the first aspect at first sight it may seem that now this circuit operates in autonomously (Akhmetov et al., 2006).

However, not everything has been done here. For example, acquired imagery data requires processing, namely – matching of imagery fragments, in a ground-based center. It is not absolutely acceptable for users who need real-time information. Besides, currently signature imaging technique is under research.

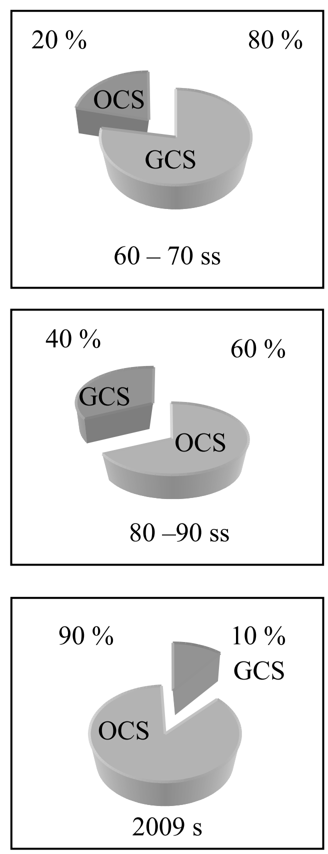


Fig. 9. Diagram of tasks distribution between onboard and ground control system: OCS – Onboard control system; GCS – Ground control system.

As for improving of imagery data descriptiveness, special imagery restitution methods shall be implemented for denoising (for example, elimination of smearing effect).

Satellite and orbital constellation control tasks are distributed between ground control system and onboard control system. They interact via information flows between mission control center, receiving station and satellite, satellite and special purpose center. Here, besides transmission of control operations during communication sessions, operating programs for arrangement of onboard and research hardware functioning and single commands, there is transmitted telemetry information and house-keeping data. Autonomy in this case is possible only when informational interchange between ground-based and onboard control systems fails by some reason. In case of telemetry data lack, necessary data may be obtained together with the housekeeping data. If it is impossible to uplink data about the scheduled areas to be imaged, it is feasible to have satellite operating completely autonomously, i.e. imaging the previously scheduled regions.

6.4. Criteria of in-built self-integration level

Control system response on modifications normally leads to consequences suppression. Therefore it is necessary to develop control methods responding not only on modifications, but also on rate of these modifications rise. Here comes necessity to create self-organizing systems. In the case under consideration it is possible to have structural, engineering, parametric and probably informational self-organization, autonomous reconfiguration of onboard systems, functional and control processes. It is especially urgent in case of anomaly, when it is necessary to maintain integrity and continuity of functional tasks solution.

Numerically this criterion can be determined by various indexes, namely:

- Coefficient of satellite operational readiness to execute basic functional tasks,
- Minimum time necessary for satellite to perform restorative function in case of anomaly,
- Quantity of possible structures and ways of satellite systems' reconfiguration,
- Relative volume of onboard sortware realising satellite control pattern in case of anomaly,
- Number of descriptors (faults in the satellite hardware) necessary from switching from nominal flight to anomaly mode,
- Amount of checking information about satellite functioning sufficient for application of reverse engineering during analysis and recovery of the satellite functionability,
- Minimum intensity of satellite switching from nominal flight to anomaly mode,
- Decrease the number of severe faults to the total number of failures.

To formulate an integrated criterion for estimation of system autonomy it is necessary to standardize all partial criteria, for example, to have them dimensionless. Then the integrated criterion may be determined by any known way (for example, additive or multiplicative convolution of partial criteria, distance estimation between alternative under consideration and its ideal representations).

Criterial estimation of autonomy by the numerical method (criteria convolution) is problematic, as observed criteria are of different nature and possess multifactor indeterminate form. In this case application of artificial intellect and, in particular, fuzzy logic methods in which are used not exact numbers but loose linguistic variables is challenging.

7. CONCLUSION

The paper covers a wide range of problematic aspects regarding autonomous functional control of low-orbit satellites, in-flight coordinate tasking for the attitude control system, onboard signature imaging systems, adaptive autonomous remote sensing space systems with intelligent control. There are suggested approaches for determination of autonomous navigation criteria.

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