Some Features of a Small Spacecraft Application as a Technique for the World Ocean Exploration

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Abstract. Nowadays, space technique is increasingly being used to solve various problems that are not directly related to outer space. One of such problem is the World Ocean exploration by means of Earth's remote sensing. Middle-class spacecrafts for Earth's remote sensing are well known, e.g. Resource-P, Spot 8, etc. They have complete attitude control systems and control systems of orbital motion. Using these spacecrafts, it is possible to obtain high-quality information about sea currents, sea animal migrations, environmental conditions, etc. However, such projects are expensive and require a long period of implementation. For this reason, small spacecrafts are widely used now. In contrast with the middle-class spacecrafts, they have a variety of features. The small spacecraft mass does not allow to place a complete attitude control systems and control systems of orbital motion on its board. On the other hand, the small spacecraft moving is little-known. The main perturbing factors for the medium-class spacecraft are aerodynamic and gravitational. The main perturbing factor for the small spacecraft is the magnetic moment. Small spacecraft orbital moving significantly affects on the quality of transmitted to Earth telemetric data. It also affects on the reliability of data about the World Ocean obtained from the small spacecraft. Therefore, the analysis of the small spacecraft rotational motion for Earth's remote sensing is an important and urgent task. Its solution will allow to obtain qualitative data and to use the small spacecraft for the World Ocean exploration.

1. Introduction

To analyze the spacecraft rotational motion, the Earth's magnetic field onboard measurement data are often used. These data are used by the spacecraft's orbital motion control system when spacecraft motion is controlled. The magnetometers application for medium-class spacecraft began in the era of the first spacecraft launches, so the problem of the Earth's magnetic field measurements correctness by means onboard equipment of medium-class spacecraft was studied fairly well [1]. The widespread application of small spacecraft makes this problem urgent again. This is due to the fact that the small spacecraft internal space is significantly smaller than the middle-class spacecraft internal space. Therefore, the scientific equipment, measuring instruments and other components of the spacecraft are located much closer to each other. It leads to the fact that the magnetic fields that arise during the
operation of various systems significantly affect on magnetometer measurement data. Therefore, before switching on the actuators, as well as when evaluating the rotational motion parameters, it is necessary to verify the measurement data accuracy.

Magnetometers are not the only information source for the evaluation of rotation parameters for AIST 2D small spacecraft, besides gyros is installed on spacecraft board. In this case, it is much easier to analyze the measurement data accuracy by comparing the measurement data from various equipment (magnetometers and gyros) [2]. However, the magnetometers in the MAGKOM scientific equipment were the only information sources about the rotational motion for uncontrolled flight of AIST small spacecraft technological and flight models [3]. The authors [4] used only one of the two magnetometer sensors measurements data during the orbital motion reconstruction of the AIST small spacecraft technological and flight models based on conducted test of the correspondence between the measurement data and the Earth's standard magnetosphere model.

The authors proposed a simple stationarity integral test for the Earth's magnetic field measurements data by means onboard equipment [5]. It is based on the stationarity hypothesis of the mean-orbit value of the Earth's magnetic field induction vector's modulus on a certain time interval. An algorithm of using this test is proposed [5] to verify the measurement data accuracy of two different magnetometers included in the MAGKOM scientific equipment [6]. This test confirms that with an unlimited increase in the measurement sessions number, the mean value of the Earth's magnetic field induction vector's modulus for the measurement data for all sessions should tend to the mean-orbit stationary value, and the dispersion asymptotically tends to zero. However, in [5] it is proposed to use all the each measurement session data. It can complicate the test's using, since in general the measurement sessions contain a non-integer number of small spacecraft's turns around the Earth. Due to the significant Earth's magnetic field inhomogeneity along the small spacecraft orbit, a situation may arise when the turn's non-integral parts be caught in the minimum values area (area 3 and area 4 in Figure 1) or in the maximum values area (area 1 and area 2 in Figure 1) of the Earth's magnetic field induction vector's modulus. This possibility is indicated in [5]. At the same time, the sample may not always be statistically reliable.

![Figure 1. The Earth's magnetic field lines scheme.](image)

2. Methods
In the paper we propose to improve the algorithm. It can be achieved by including for the measurement data analysis only full turns of small spacecraft around the Earth. The effectiveness
study of such approach is given below based on a dispersion analysis of the mean-orbit values of the Earth's magnetic field induction vector's modulus.

In our study we use the Earth's magnetic field measurements data obtained by means of the MAGKOM scientific equipment. They were carried out from 25 April to 29 May 2013 on the AIST small spacecraft flight model [7]. More detailed information is presented in Table 1.

Table 1. General characteristics of measurements data by means the MAGKOM scientific equipment.

| Date       | Sample size | Outlying cases | Number of turns per measurement session | Total sample size |
|------------|-------------|----------------|----------------------------------------|------------------|
|            |             | Sensor 1 Sensor 2 |                                        | Sensor 1 Sensor 2 |
| 25.04.2013 | 180         | 0               | 0.2                                    | 180              |
| 27.04.2013 | 1150        | 1               | 1.2                                    | 1329             |
| 29.04.2013 | 400         | 1               | 0.6                                    | 1729             |
| 10.05.2013 | 1350        | 0               | 1.7                                    | 3079             |
| 14.05.2013 | 2350        | 1               | 2.6                                    | 5428             |
| 16.05.2013 | 1699        | 221             | 2.1                                    | 6906             |
| 20.05.2013 | 1750        | 42              | 2.3                                    | 8614             |
| 27.05.2013 | 2678        | 0               | 3.5                                    | 11355            |
| 29.05.2013 | 2921        | 0               | 3.6                                    | 11355            |

We have chosen as an effectiveness criterion the dispersion of the mean-orbit value of the Earth's magnetic field induction vector's modulus. Then we estimated the random variables numerical characteristics compiled of the mean values of the Earth's magnetic field induction vector's modulus in one measurement session. At the same time, for each of the two sensors we made four random variables:
- using all measurement data (1);
- using only full turns, excluding data from the beginning of each measurements session (2);
- using only full turns, excluding data from the end of each measurements session (3);
- using only full turns, excluding data from the beginning or the end of the measurements session (depending on which value is closer to the mean for all measurement sessions) (4).

These estimates are shown in Figure 2 and 3.

Figure 2. The mean-orbit value of the Earth's magnetic field induction vector's modulus for various random variables.
3. Results and discussion
These dependences show that in the compilation of various random variables, the mean sample values vary slightly (less than 5% for the sensor 1 and slightly more than 1% for the sensor 2). However, the dispersion varies much more significantly (more than 37 times for the sensor 1 and more than 23 times for the sensor 2 when comparing the first and fourth random variables).

Thus, it was proposed the improvement the algorithm for checking the magnetometer sensors correct operation. It allows to more accurately and clearly determining the tendency to zero of dispersion of total sample when total sample increases. Therefore, the conclusion about the magnetometer sensors correct operation can be made more confidently. On the other hand, in this case it is not necessary to analyze the spacecraft position at the beginning and at the end of the measurements because in the total sample formation only full turns of spacecraft around the Earth are used.

4. Conclusions
The following conclusions can be made about the studies we carried out.
1. Measuring equipment of the Earth's magnetic field induction vector onboard small spacecraft, intended for the World Ocean exploration, are insensitive to random fluctuations of this vector. Therefore, when evaluating the measuring equipment correct operation, the stationarity hypothesis of the mean value of the Earth's magnetic field induction vector's modulus can used.
2. The proposed improvement of the algorithm for checking the measuring equipment correct operation makes it possible to more effectively assess the measuring means work quality. In this case, the checking algorithm is greatly simplified, since it does not require an analysis of the small spacecraft position in orbit.
3. Checking the measuring equipment correct operation on the flight and technological models of AIST small spacecraft by improved algorithm showed the measurement data accuracy for both magnetometer sensors.

5. References
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