Scientific and educational practice-oriented complex for training specialists in end-to-end technologies of space remote sensing of the Earth

Victor Soifer[1], *Vadim* Salmin[2], *Gennadiy* Anshakov[2], *Ivan* Tkachenko[2,*], *Sergey* Safronov[2], *Maksim* Ivanushkin[2], and *Anastasiia* Krestina[2]

[1]Department of Technical Cybernetics, Samara National Research University, 34, Moskovskoye shosse, Samara, 443086, Russia
[2]Department of Space Engineering, Samara National Research University, 34, Moskovskoye shosse, Samara, 443086, Russia

Abstract. This work is devoted to the development of a scientific and educational complex of competence and training of world-class specialists in end-to-end technologies of space remote sensing of the Earth. The complex is aimed at developing the competencies of students at all stages of the process of creating space-based means of remote sensing of the Earth—from design, production, testing and operation to processing space images and hyperspectral data and the formation of the final information product using modern digital technologies. End-to-end educational technology from the project to the final information product for a wide range of customers (data received from satellites are used by about 200 different Russian ministries and departments) formed the basis of the scientific and educational activities of Samara University.

1 Introduction

Space exploration of the Earth from space has been carried out for more than 60 years, providing people with an increasing amount of necessary and useful information. Without up-to-date and high-quality information about the state of objects and phenomena of interest related to the Earth's surface and the atmosphere, it becomes impossible to conduct effective activities in the field of meteorology, ecology, economics and many other types of human activities.

The development of Earth remote sensing (ERS) means is progressing at an increasing pace. In the period from 2006 to 2015, two to three dozen remote sensing satellites were put into orbit every year, and in the last five years there has been an exponential growth in the number of launched vehicles due to the deployment of multi-satellite space observation systems [1].

The most general trend is the increase in the frequency and resolution of the optical-electronic equipment of the ERS satellites, as well as the active development of new spectral ranges (ultraviolet and infrared parts of the spectrum). Obviously, the observation frequency is directly related to the swath of the spacecraft and, therefore, to the altitude of its orbit.

*e-mail: tkachenko.is@ssau.ru

Orbital altitude is not the only orbital parameter that determines the frequency (much depends on the inclination of the orbit and its eccentricity), but it is the need to achieve a high observation frequency that mainly determines the launch of satellites into higher orbits. The high frequency of observation is designed to identify rapidly occurring changes in objects of observation. High-resolution shooting in the "live video" mode is aimed at the same.

In recent years, an alternative way of ensuring a high observation frequency has been clearly identified based on the deployment of multi-satellite constellations of high-resolution optoelectronic observation in relatively low orbits [2]. One example of the implementation of this approach was demonstrated by the company "Planet Labs", which has formed a constellation of more than 200 spacecraft, mainly cubsats. They provide images with a resolution of 3–5 m of the entire surface of the Earth with a frequency of one day. At the same time, the trend of "large" satellites is aiming at the maximum resolution for space imagery of about 10 cm, and the trend of minisatellites generally tends to a resolution of 30–50 cm. An increase in spatial resolution and ground swath leads to a significant increase in the amount of information transmitted to ground receiving points.

Multispectral and hyperspectral observations made in the range of visible waves, ultraviolet and infrared ranges are the next natural step in the development of remote sensing. Collecting information in narrow ranges of the spectrum allows to achieve better object recognition based on their spectral characteristics. However, it should be understood that the amount of data produced by hyperspectral equipment increases many times over. This, of course, imposes new requirements on the characteristics of the transmitting and receiving path, on-board memory, and ground means information reception.

The above indicates significant changes in the approaches to the development of modern means of remote sensing [3]. The principle of consistency is still dominant and applies to all stages of the life cycle of spacecraft and monitoring systems: design (including ballistic)—manufacturing—testing—ensuring launch into a working orbit—target functioning—receiving and processing images—forming a thematic product. Thus, we are talking about the formation of an end-to-end technology for space remote sensing of the Earth. This requires new approaches in the training of specialists to ensure the development of advanced remote sensing means. Such specialists must possess a wide range of modern knowledge, skills and practical skills that allow the creation and effective operation of satellite and monitoring systems.

The main goal of this work is to provide training of world-class specialists with knowledge and competencies in all stages of the life cycle of space remote sensing systems. This makes it possible to solve the problems of staffing a scientific and technological breakthrough in the rocket and space industry.

2 Prerequisites for the creation of a scientific and educational practice-oriented complex

The advanced experience accumulated by Samara University in the training of highly qualified specialists is a catalyst for the introduction of innovative forms of scientific and educational activities at the university in the following areas:

- solution of fundamental and applied problems relevant to aerospace science, technology and engineering;
- transition to digital technologies for creating and supporting the life cycle of products (CALS-technologies) of aircraft engineering, engine building and space engineering;
- supercomputer and grid technologies for creating computer models of aircraft and space technology products, databases of electronic models of aircraft, engines and their systems;

- development of innovative production technologies: magnetic-pulse, electrochemical, ion-plasma, laser processing of materials, nanotechnology, technologies for rolling high-strength aluminum strips, vibration protection devices based on metal-rubber material, development of space biomedical devices;
- development of software and hardware for geoinformation systems, databases and services for high-precision, operational spatial modeling of territories based on Earth remote sensing data;
- personnel and scientific support for the creation of aerospace technologies, geographic information systems and Earth remote sensing systems;
- meeting the needs of the economy and national security with new geoinformation technologies and databases;
- integrated use of space images and Earth remote sensing data for global positioning systems;
- radical renewal and modernization of the content and forms of educational activities in the direction of intensifying the introduction of the results of scientific research into the educational process, the use of innovative educational approaches (polyprofessional, project, problem-search forms) that increase the motivation of students to acquire knowledge on their own.

Over the past years, Samara University has been consistently improving its performance in both Russian and international rankings. One of the most important results of the program for increasing the competitiveness of Samara University among the world's leading research and educational centers was a significant increase in the number of foreign students (from 150 people in 2012 to 1000 people in 2020), which ensures the export of Russian aerospace education abroad and promotes the achievements of Russian cosmonautics.

2.1 Cooperation with "Space Rocket Center "Progress"

The most important area of cooperation between the university and organizations in the rocket and space industry is the training of specialists and the creation of branches of base departments at enterprises. The result of this work was the long-term scientific and technical relations of the university with enterprises for targeted training and retraining of specialists, the involvement of leading specialists of the enterprise in giving lecture courses and supervising diploma design; training of scientific personnel through postgraduate study from among the specialists of enterprises.

Interaction between Samara University and the leading enterprise of the Samara rocket and space cluster Joint Stock Company "Space Rocket Center "Progress" (JSC "SRC "Progress") has a long history and is expressed in the following:

1. Targeted training of postgraduate and master's students for the "SRC "Progress".
2. Joint preparation and publication of papers, monographs [4].
3. Joint participation in large scientific and technical projects.
4. Participation of specialists of the enterprise in the work of branches of departments at the enterprise.
5. Joint organization and holding of scientific and practical conferences, symposia, seminars and educational events.

The enterprise has established a branch of the Department of Space Engineering. Classes are also held in the laboratories of strength, thermal vacuum, special tests of the research and testing complex of the enterprise. Students of the 4th and 5th years of the Department of Space Engineering have the opportunity to get acquainted with real technology at their workplaces. A unique innovative form of improving the system of university training of specialists is the conduct of industrial practice in Baikonur and Vostochny cosmodromes.

2.2 Cooperation with the Russian Academy of Sciences

Samara University maintains close cooperation with the Institute of Image Processing Systems (IIPSI) of the Russian Academy of Sciences (supervisor—President of Samara University, Academician of the Russian Academy of Sciences, Doctor of Technical Sciences, Professor V.A. Soifer). The Institute is integrated into the Samara University, actively cooperates with the university scientists in carrying out research work and successfully implements its achievements in the educational process—in the training of bachelors, masters, engineers and highly qualified personnel.

Samara University and IIPSI RAS jointly organized at the university and are successfully developing a laboratory of breakthrough technologies for remote sensing of the Earth. The main scientific areas of research at the RAS, in which scientists from the Samara University take part:

- computer optics, nanophotonics, optical information technologies and systems [5];
- image analysis and pattern recognition systems;
- geoinformation technologies.

The interaction of the university and academic structures, and primarily with the IIPSI RAS, plays a decisive role in improving the quality of fundamental training of highly qualified specialists, as well as the level of scientific research.

3 Scientific and educational practice-oriented complex for training specialists in end-to-end technologies of space remote sensing of the Earth

As part of the development of a scientific and educational practice-oriented complex of interdisciplinary study programs and laboratory testing facilities for training specialists in end-to-end technologies of space remote sensing of the Earth, interdisciplinary practice-oriented educational programs have been developed, tested and successfully implemented for 16 years. In addition, unique laboratory testing facilities have been created and integrated into the educational process, which allow for the development of the stages of end-to-end technology for creating remote sensing space assets.

3.1 Interdisciplinary study programs

The main programs developed with the participation of representatives of JSC "SRC "Progress" and IIPSI RAS, implementing the training of specialists in end-to-end remote sensing technologies:

- 24.05.01 "Design, production and operation of rockets and rocket-space complexes" (specializations: "Manned and automatic spacecraft and systems", "Modeling and information technologies for the design of rocket-space systems", "Rocket-space composite structures"), qualification—specialist;
- 24.03.01 "Rocket complexes and astronautics", qualification—bachelor;
- 11.05.01 "Radio-electronic systems and complexes" (specialization: "Onboard radio-electronic systems of rocket and space technology", "Radio-electronic systems of information transmission", "Antenna systems and devices"), qualification—specialist;

- 03.04.01 "Applied mathematics and physics" (specialization: "Mathematical modeling and information technology in photonics", "Space information systems and nanosatellites. Navigation and remote sensing of the Earth"), qualification—master;
- 01.04.03 "Applied Mathematics and Informatics" (specializations: "Mathematical Modeling and Computational Technologies", "Data Science", "Mathematical Methods for Modeling and Functional Design of Information Optical Systems and Devices", "Intelligent Data Analysis"), qualification—master.

Distinctive features of the developed educational programs are:

- enhanced fundamental training, which forms the basis for mastering special disciplines;
- high level of digitalization of both the educational process and the production process of creating remote sensing space vehicles;
- training in end-to-end technologies of space remote sensing, which forms knowledge and competencies throughout the life cycle of space technology products;
- the interdisciplinary nature of educational programs, suggesting a wide range of areas taught at the intersection of disciplines (flight dynamics and strength of spacecraft; design and optical systems; design and information technology);
- constant updating of the content of educational programs, taking into account the latest achievements of domestic and world space science and technology;
- the widespread use of individual educational trajectories, as well as the formation of conditions for the implementation of the "education throughout life" approach.

The developed programs provide personnel support by highly qualified specialists at all stages of the end-to-end technology for creating spacecraft for remote sensing of the Earth: from the design stage of a spacecraft to the stage of obtaining an information product.

3.2 Laboratory testing base

In the period from 2006 to 2021, unique laboratory testing facilities were created and integrated into the educational process, which allow the development of the stages of the end-to-end technology for creating remote sensing space assets, namely:

1. Center for receiving and processing space ERS information.
2. Supercomputer cluster "Sergey Korolev".
3. Manufacturing and testing complex of small satellite.
4. Ground control complex for small satellite of the "AIST" series.

Technical requirements for the purchased equipment for the installations being created were formed, methodological support was developed that allows using the above installations not only in the research and production process, but also deeply integrating them into the educational process, making them an integral part and the main tool for the acquisition of practical skills of working with modern equipment and technologies.

3.2.1 Center for receiving and processing space ERS information

The center is equipped with unique equipment: hardware and software complexes in the direct reception mode receive satellite imagery data from Terra/Aqua, SPOT 2/4, IRS-P5/P6, EROS A/B, RADARSAT 1/2 satellites (figure 1). Since 2010, the center has become the first in Russia certified to work with RADARSAT-2 radar data.

Figure 1. Center for receiving and processing space ERS information

The center has developed an automated system for monitoring and assessing the economic potential of the agro-industrial complex of the Samara region. The work is entirely based on satellite images. An educational and research software package for space monitoring in the field of environmental monitoring, nature management and land control has been developed. The data of the center are used, for example, in a laboratory workshop, in course and diploma design, in dissertation research carried out by graduate students and doctoral students of the university.

3.2.2 Supercomputer cluster "Sergey Korolev"

The tasks of the cluster are scientific research and training of personnel using scientific and educational supercomputer and grid technologies, the creation of competitive models of new technology in conjunction with the enterprises of the aerospace cluster. The supercomputer is used to simulate products of rocket and space technology at all stages of the life cycle, to optimize technological, production processes, and enterprise management processes (figure 2). It is equipped with the most modern CAD/CAM/CAE/PDM/PLM systems and licenses for their academic and commercial use. The supercomputer is connected to the leading industrial enterprises of the aerospace cluster by dedicated fiber-optic lines.

Figure 2. Supercomputer cluster "Sergey Korolev"

The cluster's capacity is constantly growing, and the supercomputer currently provides a peak performance of 40 trillion floating point operations per second (40 teraflops).

3.2.3 Manufacturing and testing complex of small satellite

The manufacturing and testing complex (MTC) of small satellite was created in the period from 2013 to 2015 on the basis of the experimental research building of JSC "SRC "Progress", located on the campus of Samara University. The material equipment of the MTC makes it possible to carry out key stages of testing and experimental development, as well as assembly of small spacecraft (figures 3–6). In addition, the production and testing complex is a permanent site for laboratory, practical work, as well as practices. Students have the opportunity to work on the equipment used to create real samples of space technology, primarily small ERS spacecraft and nanosatellites.

Figure 3. Climatic chambers KTK-3000 (left) and Feutron 3524/58 (right)

Figure 4. Vibration Test System DataPhysics, LE-2016/DSA10-200K

Figure 5. High vacuum chamber

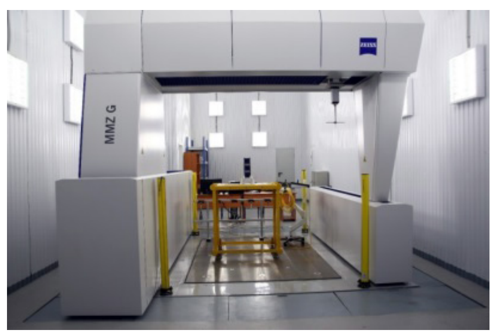

Figure 6. Coordinate Measuring Machine

3.2.4 Ground control complex for small satellite of the "AIST" series

The ground control complex (GCC) for small satellite was created in 2015 to ensure the operation of small satellite of the "AIST" series (figure 7) [6]. The staff of the center—students and postgraduate students—work in several main areas [7, 8]:

- reception, processing and in-depth analysis of telemetric information from the "AIST" series small satellite and the implementation of scientific research on its basis;
- development of projects for new small satellite based on unified platforms "AIST";
- implementation of the educational process and the development of new educational programs with deep implementation of the results of the functioning of the small satellite.

The implementation and modernization of individual disciplines and educational programs as a whole is carried out on an ongoing basis for the training of specialists, bachelors

Figure 7. Ground control complex for small satellite of the AIST series

and masters of Samara University by introducing the results of the functioning of the constellation of "AIST" small satellites into the educational process.

3.3 Small satellite "AIST-2D"

The "AIST-2D" small satellite (figure 8) is the most striking example of the practical application of the developed scientific and educational practice-oriented complex of interdisciplinary educational programs and laboratory testing facilities for training specialists in end-to-end technologies of space remote sensing of the Earth. The design of the apparatus was carried out entirely in "digital form" using modern technologies of top-down design, which allows to ensure the simultaneous work with the product of different groups of performers and the constant "linking" of all parameters of the satellite [9]. The device was manufactured using modern technological solutions using high-tech production equipment. Ground experimental testing of the satellite was carried out in a short time and in the minimum volume, which at the same time ensured the required level of reliability.

Figure 8. The "AIST-2D: small satellite

The creation of the satellite by specialists from Samara University and JSC "SRC "Progress" (mostly graduates of Samara University) in a record-breaking time for the industry—32 months (from design to launch and obtaining information) is also a confirmation of the effectiveness of the developed methodological approaches to training. Such a speed of creation of fundamentally new ERS space assets is a world-class achievement.

The processing of images received from the apparatus is carried out using algorithms and software created by specialists from the Samara University and the IIPSI RAS in conjunction with specialists from the JSC "RSC "Progress" [10].

4 Results

The developed scientific and educational practice-oriented complex of interdisciplinary curricula and laboratory testing facilities is designed to train specialists in end-to-end technologies of a dynamically progressing industry—space remote sensing of the Earth.

Based on an interdisciplinary approach and the implementation of individual educational trajectories, the formation of students' competencies at all stages of the life cycle of the ERS space system is provided—from design and testing of a spacecraft to thematic image processing.

The end-to-end technology of creating ERS spacecrafts from the project to the final information product for a wide range of customers formed the basis of the scientific and educational activities of Samara University. This made it possible to provide training for specialists with knowledge, competencies and skills in all stages of the life cycle of the ERS space system, and to solve the problem of staffing a scientific and technological breakthrough in the rocket and space industry. The end-to-end educational training of specialists in space ERS is based on fundamentality, multidisciplinarity, the implementation of the concept of "education through research", the inextricable connection of education with industrial practice at the JSC "SRC" Progress" and the Baikonur and Vostochny cosmodromes, a high level of digitalization, the involvement of students in a practical solution tasks of creating spacecraft.

Since the realization of the project and the implementation of its results in the educational and pedagogical activities of Samara University (2006–2021), more than 3000 specialists have been trained, employed in the industry. The work was awarded the Yuri Gagarin Russian Government Prize in the field of space activities in 2021.

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