Инновационный учебно-научный центр мониторинга лесных ресурсов Сибири на основе лазерной и микроволновой аэрокосмической съемки

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Обсуждаются возможности создания на базе кафедры космических средств и технологии Сибирского государственного университета науки и технологий имени М. Ф. Решетнева инновационного учебно-научного центра мониторинга лесных ресурсов Сибири с целью подготовки инженерных кадров высшей квалификации и проведения перспективных научных исследований в области мониторинга, моделирования, прогнозирования и управления лесными ресурсами. Предлагаются методические решения и алгоритмы трехмерного моделирования структуры и динамики леса по данным лазерного сканирования, цифровой аэро- и космической съемки. Эти методы способствуют оперативному мониторингу и позволяют значительно снизить стоимости по контролю состояния и использования лесных ресурсов на огромной территории Сибири. Данные дистанционного зондирования представляются в виде геотрансформированной базы данных и цифровой фотокарты, совместимых в форматах с системами автоматизированного проектирования и основными геоинформационными системами – ArcView, ArcINFO, MapINFO. Инновационный центр мониторинга будет использован для оперативного государственного контроля и мониторинга лесопользования, состояния лесных земель, лесоустройства и инвентаризации лесов; решения задач экологии и природопользования, геоэкологии; формирования кадастра лесных ресурсов; аэрокосмических методов исследования природных ресурсов и территорий, информационных технологий. Решение данных задач позволит осуществлять подготовку специалистов высокой и высшей квалификации. Специалистами центра планируется создавать информационные технологии дистанционного зондирования природных объектов с целью импортозамещения зарубежных программных продуктов. Основные научные направления создаваемого центра: разработка и исследование методики системного анализа многомерных данных дистанционного зондирования большого объёма на основе непараметрических алгоритмов принятия решений и технологий параллельных вычислений; проверка гипотез о распределениях данных дистанционного зондирования большого объёма, основанных на непараметрических алгоритмах распознавания образов ядерного типа; обнаружение компактных групп данных дистанционного зондирования большого объёма, соответствующих одномодальным фрагментам совместной плотности вероятности многомерных случайных величин.

Ключевые слова: инновационные методы дистанционного зондирования лесов, программные средства, моделирование, подготовка инженерных кадров высшей квалификации, Сибирь, Красноярский край.

Innovative educational and research center for monitoring forest resources of Siberia based on laser and microwave aerospace imaging

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The possibilities of creating an innovative educational and scientific center for monitoring forest resources in Siberia on the basis of the Department of Space Facilities and Technologies of the Reshetnev Siberian State University of Science and Technology are discussed, with the aim of training highly qualified engineering personnel and conducting promising scientific research in the field of monitoring, modeling, forecasting and management of forest resources. Methodological solutions and algorithms for three-dimensional modeling of forest structure and dynamics based on laser scanning data, digital aerial and space photography are proposed. These methods contribute to operational monitoring and can significantly reduce the cost of monitoring the condition and use of forest resources over the vast territory of Siberia. Remote sensing data is presented in the form of a geotransformed database and digital photo map, compatible in formats with computer-aided design systems and with the main geographic information systems – ArcView, ArcINFO, MapINFO. The innovative monitoring center will be used for operational state control and monitoring of forest management, the state of forest lands, forest management and forest inventory, solving problems of ecology and environmental management, geoecology, formation of a forest resource inventory, aerospace methods for studying natural resources and territories, information technology. Solving these problems will allow for the training of highly qualified specialists. The center's specialists plan to create information technologies for remote sensing of natural objects with the aim of import substitution of foreign software products. The main scientific directions of the created center: development and research of methods for system analysis of large-scale multidimensional remote sensing data based on nonparametric decision-making algorithms and parallel computing technologies; testing hypotheses about the distributions of large-volume remote sensing data based on nonparametric nuclear-type pattern recognition algorithms; detection of compact groups of large-volume remote sensing data corresponding to unimodal fragments of the joint probability density of multivariate random variables.

Keywords: innovative methods of remote sensing of forests, software, modeling, training of highly qualified engineering personnel, Siberia, Krasnoyarsk Krai.

Introduction

The most important component of the biosphere and a source of resources are forests. The timely provision of information about their state allows for sustainable forest management, environmental control and protection, and research in the field of global biosphere and climate changes. The need to monitor the vast forest areas of Siberia allows us to consider remote methods as priority sources of information about the state and dynamics of forests, which determines the relevance of the development of appropriate methods for processing the received data. The use of Earth remote sensing (ERS) methods provides a sufficient level of data reliability on the state of forest cover, including ones for measuring key characteristics of forest biomass. Remote sensing methods such as ground-based (TLiDAR) and airborne laser scanning (LiDAR), digital aerial photography from aerial vehicles, including unmanned aerial systems (UAS), and satellite images are used. The use of innovative aerospace meth-

ods for sensing land covers (laser, microwave aerial and space photography, satellite geopositioning) provides fundamentally new opportunities for monitoring forest resources in the vast expanses of Siberia. The high efficiency of pulsed laser ranging in combination with the submeter spatial resolution of microwave aerial and space photography, and nonparametric pattern recognition methods make it possible to develop an effective system for assessing the actual state of forests. Three-dimensional modeling of forest vegetation is a primary task when constructing forest landscape scenes, since it is high-quality vegetation models that are responsible for realistic visualization of three-dimensional scenes of forest areas. In addition, mathematical modeling of vegetation using laser scanning data makes it possible to calculate reliable and highly accurate biomass parameters and morphometric indicators of planting structure [1–11].

Modern methods of comprehensive analysis of remote sensing data are the basis for the creation of regional geographic information systems that ensure the efficiency of obtaining the required information and support management decisions. Increasing the efficiency of processing large amounts of remote sensing data based on non-parametric information processing systems is an urgent task and ensures import substitution of foreign software products. Their use will significantly improve the accuracy and efficiency of solving problems of decision support based on remote sensing data. It is expected to create methods for comprehensive analysis of remote sensing data, which will become the basis for solving the most important problems in the development of natural resources of the North and Siberia, related to the study of the spatio-temporal dynamics of the states of forests [12–17].

1. Grounds for creating the center

The development and implementation of such a highly effective complex of forest monitoring and forest management in Siberia is an extremely urgent task, since forest management data is largely outdated (30 years or more) and does not reflect the real state of forests due to logging and fires. Traditional methods of inventory of forest resources today are not effective and do not provide the required accuracy, and are also high in cost and execution time [2–5; 9; 18] (fig. 1, 2).
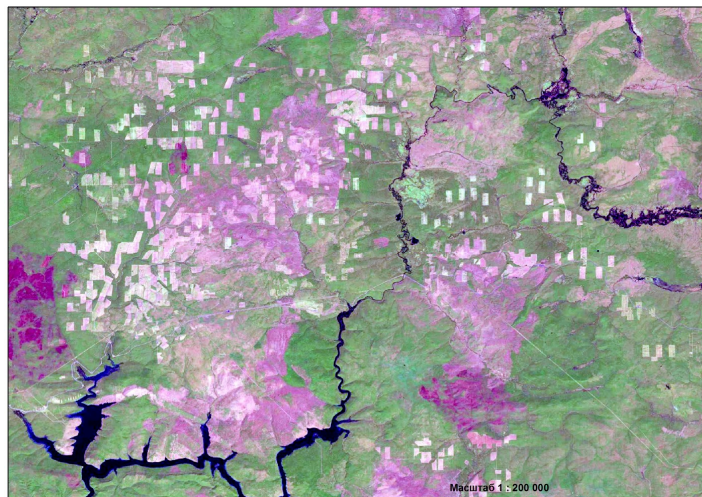

Рис. 1. Вырубки арендной территории Лесосибирского ЛДК № 1
(Богучанский и Кежемский районы Красноярского края). Спутниковый снимок Landsat-8TM, 2022 г.

Fig. 1. Deforestation of the leased territory of Lesosibirsk LDK No. 1 (Boguchansky
and Kezhemsky districts of Krasnoyarsk Krai). Landsat-8TM satellite image, 2022
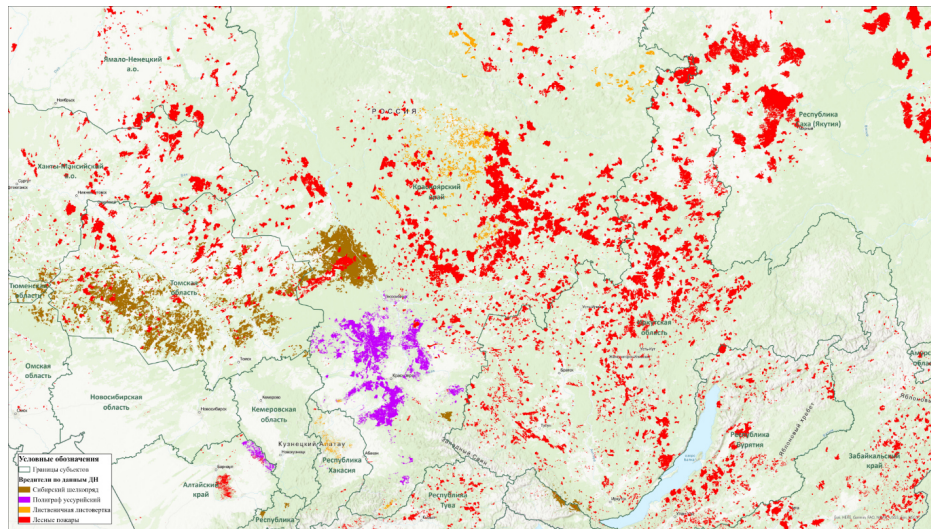
Рис. 2. Нарушенность лесов Сибири лесными пожарами и вспышками
массового размножения насекомых-вредителей

Fig. 2. Disturbance of Siberian forests by forest fires and outbreaks of insect pests' mass reproduction

The goal of the project is to create an innovative educational and scientific center for training highly qualified engineering personnel, conduct advanced scientific research in the development of new methods for remote sensing of forests and other natural resources, develop a complex of objective and high-precision control and monitoring of the state of forest resources and forest management in Siberia based on integration of laser and microwave aerial and space photography and satellite geopositioning, which are the basis of a fundamentally new system of monitoring, modeling, forecasting and forest resource management [19; 20].

The proposed integrated multisensory approach, innovative mathematical and software apparatus allow you to quickly and accurately determine the quantitative and qualitative characteristics of forests.

Proposed methodological solutions and algorithms for three-dimensional structure modeling and forest dynamics according to laser scanning data, digital aerial and space photography are pioneers contributing to more efficient operational and significantly (2 or more times) less costly and resource-intensive control and monitoring of the condition and use of forest resources over the vast territory of Siberia [21–24].

When using the method, much higher accuracy of laser and microwave determinations of biometric and taxation indicators of trees and forest stands is achieved than with traditional ground-based forest inventory work. Laser ranging and microwave scanning data are presented in the form of geotransformed (introduced into a system of real geographic coordinates) database and digital photo map, compatible in formats with computer-aided design (CAD) systems and major geographic information systems – ArcView, ArcINFO, MapINFO (fig. 3).

2. **Prospects for the center**

The development and implementation of the complex into the practice of forest management remote monitoring at the regional level will ensure the prompt receipt of up-to-date reliable and high-precision data on the state of forest resources, will provide a reliable information basis for monitoring the results of economic activities in the use of forests, will significantly increase the economic and environmental efficiency of management in the field forest management [25–27].

It is proposed to create and operate an innovative educational and scientific center within the framework of the directions of the regional technological platform of the Krasnoyarsk Krai "Innovative technologies for the integrated use of forest resources" in close cooperation with the institutes of the Federal

Research Center "Krasnoyarsk Scientific Center SB RAS", the Ministry of Natural Resources and Ecology of the Krasnoyarsk Territory, the Ministry of Forestry of the Krasnoyarsk Territory, forestry enterprises complex of Siberia.

The project corresponds to priority areas of science, technology and engineering development in the Russian Federation, critical technologies (according to the List, in the Decree of the President of the Russian Federation of July 7, 2011 No. No. 899): 04 – Information and telecommunication systems; 06 – Rational use of natural resources. Technologies for assessing resources and forecasting the state of the lithosphere and biosphere. Technologies for monitoring and forecasting the state of the natural environment. Codes and names of headings state rubricator of scientific and technical information: 25.00.34; 36.23.25; 36.29.33; 68.00.00; 68.47.31; 68.47.33; 89.57.15; 89.57.45.

Areas of commercial use of project results are operational state control and monitoring of forest management and the condition of forest lands, forestry, forest management and forest inventory, ecology and environmental management, geoecology, formation of a forest resource inventory, aerospace methods for studying natural resources and territories, information technology, training of highly qualified specialists.

Scientific background, level of practical implementation. An instrument complex and technologies for remote sensing of forests have been developed based on high-resolution pulsed laser and microwave aero- and space sensors : DJI Matrice 300 RTK, RIEGL RiCOPTER VUX-1, Leica ALS 60+RCD 30 (60 MP 6 мкм) + NovAtel OEM 5 GPS/ГЛОНАСС, WorldView-2, GeoEye-2, Radarsat II.
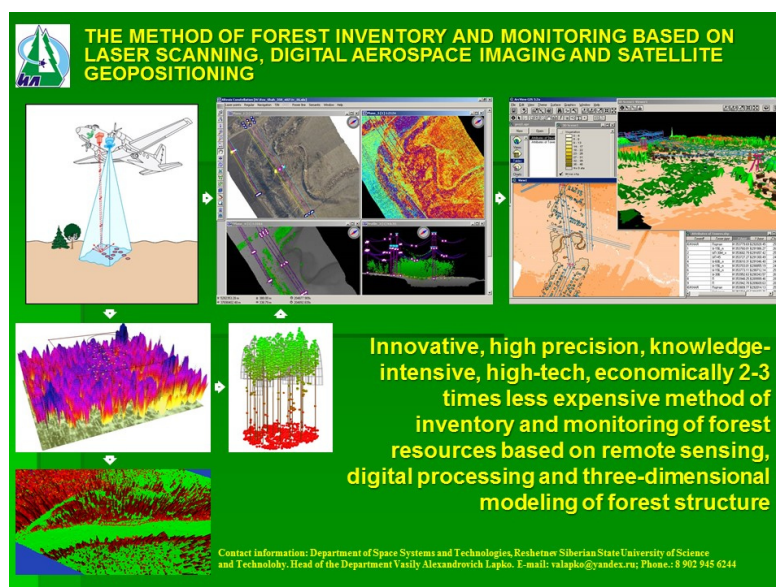

Рис. 3. Метод инвентаризации и мониторинга лесов на основе лазерного сканирования,
цифровой аэрокосмической съемки и спутникового геопозиционирования

Fig. 3. Method of forest inventory and monitoring based on laser scanning,
digital aerospace photography and satellite geopositioning

Methods and software products have been developed for assessing forest structure based on laser, microwave and digital aerial and space survey data, digital models of the earth's surface and forest cover in the regions of the Krasnoyarsk Krai. Three-dimensional digital mapping of forest areas of the Krasnoyarsk Territory was carried out on a scale of M 1:200000 and larger for the purposes of state control, detailed inventory and monitoring of forest resources, including the use of unmanned aerial systems (Fig. 4).
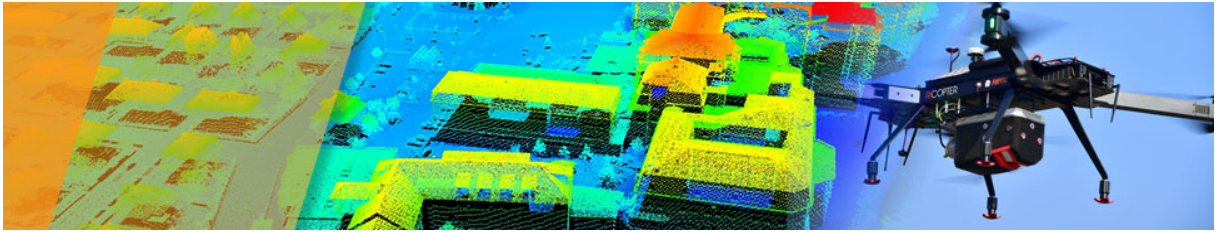
Рис. 4. Беспилотные авиационные системы лазерного сканирования и аэросъемки, используемые в проекте

Fig. 4. Unmanned aircraft laser scanning and aerial photography systems used in the project

Qualitative and quantitative composition of project performers. The project implementers include 5 doctors of science, professors, 5 candidates of science, 3 graduate students (Reshetnev Siberian State University of Science and Technology, Federal Research Center "Krasnoyarsk Science Center of the Siberian Branch of the Russian Academy of Sciences"), 2 test engineers, 5 masters and 5 bachelors of the Department of Space Facilities and Technologies Reshetnev Siberian State University of Science and Technology.

Main expected results. On the topic of the project, highly qualified personnel are trained (masters, candidates and doctors of science), more than 30 scientific articles have been published in peer-reviewed Russian and international journals, 5 monographs, 3 textbooks, 3 Russian patents have been received. The implementation of the project will make it possible to introduce a technological and software complex in the monitoring system of forest resources and forestry in the Krasnoyarsk Territory and other regions of Siberia, train highly qualified personnel, create at least 30 additional high-tech jobs, attract investments in the amount of at least 150 million rubles per year, due to funds from tenants of forest plots, forest and natural resource users.

Forms of implementation and protection of intellectual property: technology – 1; prototype – 1; copyright certificates – 3; patents – 3; certificates of state registration of computer programs – 5; educational and methodological publications – 3; articles in peer-reviewed scientific journals from the List of Higher Attestation Commission, RSCI, RSCI, Scopus, WoS (Q 1–3) – 15

Planned project budget is ~ 50 million rub. per year (2024–2028). Scientific supervisors of the project: Lapko Vasily Aleksandrovich, Doctor of Technical Sciences, Professor, Head of the Department of Space Systems and Technologies Reshetnev Siberian State University of Science and Technology; Danilin Igor Mikhailovich, Doctor of Agricultural Sciences, leading researcher at the Laboratory of Taxation and Forest Management of the Sukachev Institute of Forest SB RAS, Professor of the Department of Space Facilities and Technologies Reshetnev Siberian State University of Science and Technology.

Conclusion

As a result of the project implementation, significant budget savings will be achieved by reducing the costs of carrying out work on state control of forest use and forest inventory. Higher accuracy in determining timber reserves, reducing the error of determination results by 3–4 times, and increasing revenues to local and regional budgets for forest use by 20–25% will be guaranteed by obtaining up-to-date and reliable accounting data on the state of forests.

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