Information system for analyzing negative impacts on forests of the border regions

V A Zelentsov*, S A Potryasaev and A E Semenov

Laboratory of Information Technologies in System Analysis and Modeling, St. Petersburg Institute for Informatics and Automation of the Russian Academy of Sciences St. Petersburg Federal Research Center of the Russian Academy of Sciences (SPC RAS), 14th Line of Vasilievsky island 39, St. Petersburg 199178, Russian Federation

*Corresponding e-mail: v.a.zelentsov@gmail.com

Abstract. The article describes the architecture and composition of a software package for the creation of an information system (IS) to be used in the state of natural objects analysis, in particular, forests of the border region of Russia-South-East Finland. Information system development is carried out within the InnoForestView Project of the ENI CBC Program. The project addresses the consequences of three types of negative impacts: forest fires, diseases and insects, and the proximity of roads. It is shown that the use of a service-oriented architecture with the implementation of individual components of IS in the form of web services, as well as the proposed technologies for integrating heterogeneous information resources, including Earth remote sensing data, ensures the fulfillment of the basic requirements for IS, including the possibility of multi-temporal analysis, maximum automation of tasks to be solved, and user friendliness.

1. Introduction

One of the topical areas the Cross-Border Cooperation Program [1] is consolidation of efforts to improve the environmental situation in the region and provide access to objective data on the state of the environment. The InnoForestView project [2] addresses these issues by analyzing the negative impact on the forests of the border region of three factors: forest fires, insects and diseases, and anthropogenic impact along the roads. To carry out such an analysis new studies with the use of spatial data, including the Earth remote sensing (ERS) data, since this type of data is the main source of information for monitoring vast and hard-to-reach areas of forest, are required.

One of the main features of research and applied developments related to the use of spatial data, including ERS data, is interdisciplinary nature of these developments. Examples include the tasks of environmental monitoring, modeling the development of emergencies, forest management, etc. Interdisciplinarity arises as a consequence of the need for simultaneous use, firstly, of complex subject-oriented sets of models for assessing and predicting the state of observed natural and natural-technical objects (NNTO); secondly, heterogeneous ground-aerospace data and the results of their processing; and thirdly, tools for integrating the models and data required for implementation of specific projects and (or) creation of thematic information services with various applications.

Organizations, developers and researchers often specialize in solving modeling problems in a specific applied area without the use of modern tools for automated modeling, integrated data analysis

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and presentation of results. At the same time, information technology developers often do not have access to specialized models (polymodel complexes) for NNTO analysis and use simplified approaches to solve applied problems. In both cases, the value of the results obtained decreases. This situation is largely due to the insufficient development of methods, technologies and systems which ensure integration within a single computational process of available data on the state of NNTO, including ERS data, models of changes in the state of NNTO under normal conditions and in emergency situations, and equipped with the necessary tools to provide users with the results of calculations in an accessible and visual form, i.e. in the form of relevant thematic products and services. The analysis showed that the described problem can be solved concept of comprehensive automation and intellectualization of obtaining, processing, analyzing and practical use of heterogeneous data coming from various sources [3-5].

By finding a solution to this problem, the existing gap between the growing volumes of remote sensing data and the degree of their real use for a wide range of applied problems can be reduced. Currently, a large number of thematic services based on the use of remote sensing data are offered in Russia and abroad. However, the analyzed systems and tools [6] are focused mainly on working only with remote sensing data, while for solving applied interdisciplinary problems it is also necessary to use data and information coming from other sources (for example, from unmanned aerial vehicles, from ground measurements, data on the territory and infrastructure, etc.), as well as the results obtained using models from relevant subject areas for analyzing and predicting the state of NNTO. There are only a few known cases of providing domain models as a service for working with user data. However, such systems, combined with the possibilities of using remote sensing data in modeling, have not yet received widespread use.

The present article examines the architecture of information system (IS) and software and technological tools aimed at solving this problem.

2. Methods and Materials
The concept of integrated automation is based on the results of two areas of research. The first of them includes the development of methods and technologies for multicriteria assessment, analysis and selection of models and polymodel complexes to describe the processes of NNTO functioning, including forests, under a negative external impact. This area develops within the framework of the qualimetry of models and polymodel complexes [3], providing a methodological basis for automating procedures for selecting specific NNTO models when performing interdisciplinary projects and creating thematic information services.

The second area includes the development, selection and adaptation of architectures and software and technological solutions for the construction of systems directly intended for NNTO monitoring using remote sensing data. This area is discussed in more detail in this article.

The main functions of the developed software and technological solutions and the corresponding IS are to provide online integration of heterogeneous information resources (selected NNTO models, remote sensing data, results of ground measurements and auxiliary data), organization of interaction with external information and analytical systems, analysis and interpretation of the obtained modeling results, and their visualization and delivery to the end user in the form of thematic services. The functions listed form the basic requirements for the architecture of the created IS.

The following basic approaches to the creation of the architecture of such systems are well known [7]: monolithic architecture; modular architecture; component architecture; client-server architecture; and service oriented architecture. A comparative analysis [8] showed that the most preferable option for building an IS, taking into account the requirements, is the use of a service-oriented architecture (SOA) which implements a modular approach to software development, and the use of distributed, loosely coupled replaceable components equipped with standardized interfaces for interaction through information and telecommunication networks. SOA enables distributed use of heterogeneous resources, thereby simplifying interaction between different parts of the system, which are often supported and developed by different teams and companies. Communication of the system modules is
carried out via a service bus (Enterprise Service Bus, ESB). The service bus is a traditional SOA way of organizing "communication" between services; it has tools for centralized and unified event-driven messaging between various modules of the information system [4]. The use of this approach helps to embed complete software solutions into the information system (that do not require additional validation and verification), does not require binding to specific programming languages, and allows us to configure the information system according to current requirements. An example of an IS architecture for assessing the negative impact of various factors on the state of forests is shown in figure 1. The modules shown at the bottom left of the figure have been designed to assess the consequences of exposure to negative factors, for example, fires, diseases and insects, and proximity to roads.

The most important distinctive features of the IS that provide comprehensive automation of data processing tasks, modeling and provision of thematic services to users on the principle of "one window" are the presence of the ERS data ordering and indexing module in the information system, as well as the use of Business Process Execution Language, BPEL [7, 9]. BPEL helps to organize the logic of interaction between IS components and web services when solving each specific application problem by using, among other things, a visual editor. This provides a simple visual formation of algorithms for the system using various sources and services, and scaling the composition of the services provided according to the "constructor" principle.

To meet the requirements for the integration of heterogeneous information resources, the following software solutions have been included in the system prototype:

- software for displaying data according to the standards of web-mapping GeoServer;
- PostgreSQL spatial database management system with PostGIS add-on;
- Python-based administration server;
- data collection service;
- service for receiving, processing and downloading remote sensing data;
- forecasting services (if provided);
- service for processing and interpreting the results of calculations;
- user web interface - web application adapted for work on stationary and mobile user terminals.

The IS interface provides end users with necessary minimum of tools for working with data: search string of spatial data, list of currently displayed data and time slider for working with temporal data. The user may view various data (current, historical, and forecast) without special knowledge (for example, a formal query language) simply by moving the time slider. Thus, all the complexity associated with the use of heterogeneous geographically distributed information systems will be hidden from the user due to full automation of the computational process. This allows the system to be
used not only by specialists with a high level of knowledge in the field of GIS and information technology, but also by specialists in the subject area (forestry) and all other interested users (emergency services, executive authorities, commercial organizations and citizens).

In addition, in order to increase the fault tolerance of the information system, development and adaptation of software tools for the implementation of continuous integration technologies were carried out, including the following activities:

- deployment and configuration of Jenkins (https://www.jenkins.io);
- deployment and configuration of Kubernetes cluster (https://kubernetes.io);
- deployment of information system containers and testing (https://www.docker.com);
- setting up logging and infrastructure monitoring systems (Grafana, https://grafana.com);
- preparation and testing of a production server.

As a result of implementation of the technologies listed, stable operation of the IS is ensured when it is located on the organization’s own hardware resources and when using external cloud information resources.

3. Results and Discussion

The Federal Research Center of St. Petersburg RAS has implemented all the main IS components shown in figure 1, including the ERS data ordering and indexing module, which implements the procedures for processing remote sensing data received from the Russian satellites Resurs-P and Kanopus-V. In general, the services are based on the use of remote sensing data from both Russian and foreign (Sentinel, Landsat, etc.) satellites.

Currently, the IS provides the following opportunities:
- uploading heterogeneous spatial data,
- visualization of heterogeneous spatial data,
- interaction with external systems using their API,
- application of EO data (downloading of satellite data on the areas of interest),
- multiproject system mode,
- multitemporal analysis,
- integration of NNTO models into a single information system,
- joint analysis of heterogeneous data and modelling results,
- uploading photos, videos, and other relevant documents,
- setting up user account permissions for working with the information system.

The user interface is designed as a geoportal, so that the system is accessible from desktop computers and personal mobile devices via modern web browsers. In particular, figure 2 shows a user interface when solving the problem of analyzing the dynamics of changes in vegetation cover on the territory of the State wildlife reserve “Birch Islands” located in the Leningrad Region, for the period 2001-2019. The developed web service demonstrates ongoing changes in a given area for the time interval specified by the user. For this purpose, a timeline has been built into the user interface, and moving the slider of this scale allows the user to set the required time interval for the analysis. In figure 2, areas with significant changes in the properties of the vegetation cover (felling, drying, etc.) that occurred during the analyzed period of time are shown in dark color. The identification of changes was carried out on the basis of processing data of the Landsat satellite.

Another example is the use of IS to analyze the negative effects of forest fires. Figure 3 shows the user interface when using the service for analyzing the dynamics of forest fires in the border area of South-Eastern Finland and the Leningrad Region, as well as automatic assessment of burned forest areas using remote sensing data from Sentinel-2. The timeline is also used here to view data for the time interval of interest to the user.

Figure 4 shows examples of IS visualization of data from external information systems, or developed by various participants of an interdisciplinary project, and published in a joint information system. This example was generated during the execution of the InnoForestView project [2].
Figure 2. The IS user interface when viewing the dynamics of ongoing changes for the period 2001-2019.

Figure 3. The IS user interface when analyzing the dynamics of forest fires and identifying burned areas (data on forest fires - service https://firms.modaps.eosdis.nasa.gov/; Sentinel-2 snapshot from 25.11.2019; field research, method of detecting burned areas and a photograph by VF Mochalov).

Figure 4. Visualization examples of Finnish Multi-source National Forest Inventory data (http://kartta.luke.fi:80/geoserver/MVMI/ows) by the IS interface.
4. Conclusion
An effective way to solve the problem of combining heterogeneous distributed information resources when creating information systems for monitoring natural objects is to use a service-oriented and event-oriented architecture in combination with technologies of platform-independent universal description, automatic search and integration of web services. The results of the implementation of this approach for solving interdisciplinary problems of creating thematic services with the integrated use of ground-aerospace data and modeling results show that when using it, the basic requirements for such systems are met, including maximum automation of the tasks being solved, high reliability and user-friendliness. In general, the developed IS is a fairly universal toolkit that allows us to create convenient decision support tools in the field of forest management, ecology and environmental protection, as well as monitoring and predicting negative impacts on the environment.

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