Digital deforestation monitoring and control system: an innovative approach to the conservation of forest resources

Vladislav Lukin[1*] and *Vladimir* Zolnikov [2]

[1] Tambov State Technical University, Russia, 392000 Tambov, Russia
[2] Voronezh State Forest Engineering University named after G.F. Morozov, 394087 Voronezh, Russia

Abstract. This article presents the concept of an innovative digital system for monitoring and controlling deforestation, aimed at improving the efficiency of forest management and combating illegal logging. The system is based on the use of modern high-resolution satellite data and machine learning methods to analyze changes in forest cover. The paper describes the architecture of the proposed system, which includes modules for data collection, change analysis, classification and visualization. Special attention is paid to the potential advantages of the system, such as improving the accuracy and efficiency of detecting changes in forests. Possible problems and limitations in the implementation of the system are considered, including dependence on the quality of satellite images, requirements for computing resources and legal aspects. The proposed system has the potential to significantly improve the monitoring of forest resources, contributing to their conservation and sustainable use in the context of global climate change.

1 Introduction

Deforestation is one of the most acute environmental problems of our time, with global consequences for climate, biodiversity and humanity as a whole. Despite the fact that forests are a renewable resource, the rate of their destruction significantly exceeds the rate of natural reproduction. Every year, millions of hectares of forests disappear around the world, which leads to catastrophic consequences for the ecosystems and climate of the planet.

The scale of the problem is truly impressive: the area of tropical forests, which are home to more than 50% of the species of living organisms on Earth, has decreased from 14% to 6% of the planet's surface. In India, forest cover has decreased from 22% to 10% over the past half century. An equally alarming situation is observed in Russia, where valuable coniferous forests are being actively cut down in the central regions, the Far East and Siberia [3].

The consequences of deforestation are multifaceted and serious. These include sudden temperature changes, changes in precipitation and wind speeds, increased greenhouse effects, soil erosion, increased frequency and scale of floods, and loss of biodiversity. Continuous

* Corresponding author: wkz@rambler.ru

logging is especially destructive, which leads to the complete destruction of forest ecosystems.

It is important to note that the problem of deforestation is closely related to socio-economic factors. In many regions of the world, logging is an important source of income for local populations and national economies. However, the short-term economic benefits of uncontrolled deforestation are not comparable to the long-term damage to the environment and climate. This creates a complex dilemma that requires a balance between economic development and conservation of natural resources.

In this context, the development of effective methods for monitoring and controlling forest resources is of particular relevance. Traditional surveillance methods, such as ground surveys and aviation monitoring, are often not fast enough and large-scale enough to solve the global problem of deforestation. Modern technologies, in particular, remote sensing of the Earth and machine learning methods, open up new opportunities for creating more effective monitoring systems.

In the light of these problems, it becomes obvious that effective methods for monitoring and controlling deforestation must be developed and implemented. Modern technologies, such as remote sensing of the Earth and machine learning methods, open up new possibilities for solving this problem.

This article presents the concept of an innovative digital system for monitoring and controlling deforestation, aimed at improving the efficiency of forest resource management and combating illegal logging. The proposed system is based on the use of high-resolution satellite data and machine learning algorithms to analyze changes in forest cover.

The purpose of the study is to develop a system architecture capable of timely detecting changes in forests, classifying them and providing relevant information for management decision-making. Such a system can become an important tool in the implementation of the principles of sustainable forest management, conservation of biodiversity and mitigation of the effects of climate change.

2 Materials and methods

The proposed system is a comprehensive solution using modern digital technologies for effective monitoring of the state of forests and control of deforestation. The main purpose of the system is to timely identify changes in forest cover, including illegal logging, and provide relevant information for management decisions.

The principle of operation of the system:

1. Data collection: The system regularly receives high-resolution satellite images (for example, from Landsat-8 and Sentinel-2 satellites) every two weeks. These images cover the entire territory of the observed woodlands.
2. Pre-processing of images: The received images are pre-processed, including:
   - 2.1. Atmospheric correction to eliminate the influence of atmospheric phenomena on image quality
   - 2.2. Geometric correction for accurate snap of images to geographical coordinates
   - 2.3. Radiometric calibration to ensure comparability of data from different periods
3. Change analysis: The system uses machine learning algorithms to identify changes in forest cover. This process includes:
   - 3.1. Image segmentation to highlight homogeneous areas
   - 3.2. Classification of surface types (forest, logging, water bodies, etc.)
   - 3.3. Comparing current snapshots with historical data to identify changes
4. Classification of changes: Identified changes are classified by type:
   - 4.1. Logging (legal and potentially illegal)
   - 4.2. Fire damage

   4.3. Diseases of trees
   4.4. Natural extinction
   4.5. Reforestation
5. Scale estimation: The system automatically calculates the area of affected areas and estimates the amount of lost wood based on data on the type of forest and the average density of trees.
6. Data storage and processing: All received data is stored in a geospatial database, which allows:
   6.1. Store historical data on the state of forests
   6.2. Track the dynamics of changes over time
   6.3. Perform spatial analysis
7. Visualization and Reporting: The system provides an interface for data visualization, including:
   7.1. Interactive maps showing the current state of forests and identified changes
   7.2. Graphs and diagrams showing the dynamics of changes
   7.3. Automatically generated reports on the state of forests
8. Notification system: When critical changes are detected (for example, large illegal logging), the system automatically sends notifications to responsible persons.

Such an integrated system allows not only to effectively monitor the state of forests and identify illegal logging, but also provides tools for analyzing long-term trends in forest cover changes. This enables forestry to make informed decisions on forest resource management and develop strategies for adaptation to climate change.

To design and visualize the architecture of the proposed deforestation monitoring and control system, it is advisable to use UML modeling (Unified Modeling Language). This approach allows you to visualize the structure and functioning of the system at various levels of abstraction.

As part of the development of the system, it is proposed to use the following types of UML diagrams:

1. Use Case Diagram to define the main functions of the system and user interaction. This diagram will help identify key scenarios for using the system, such as viewing a map of forest cover changes, generating reports, and configuring alerts.

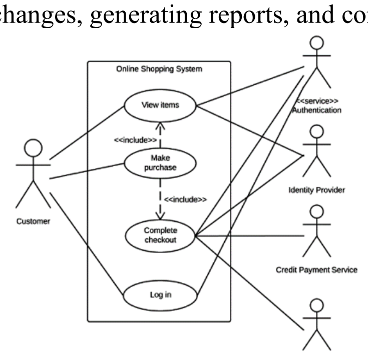

Fig. 1. An example of a use case diagram.

2. A Class Diagram to represent the structure of the system, including the main classes and their relationships. This will allow you to visualize components such as a satellite image processor, a change detector, a classifier of forest areas and an alert system.

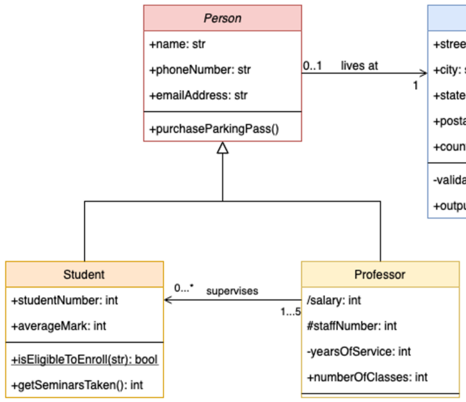

Fig. 2. An example of a class diagram

3. A Sequence Diagram to illustrate the interaction between system components over time. Using this diagram, you can present in detail the processes of processing new satellite images or generating alerts about illegal logging.

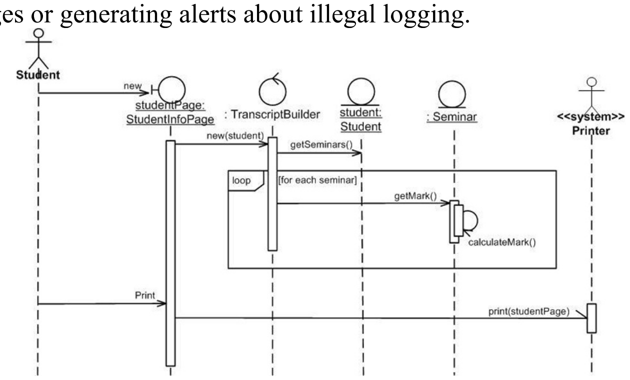

Fig. 3. An example of a sequence diagram

4. A State Diagram for displaying the various states of a system or its components. For example, you can visualize the stages of image processing or the state of forest areas (untouched, partially cut down, recovering).

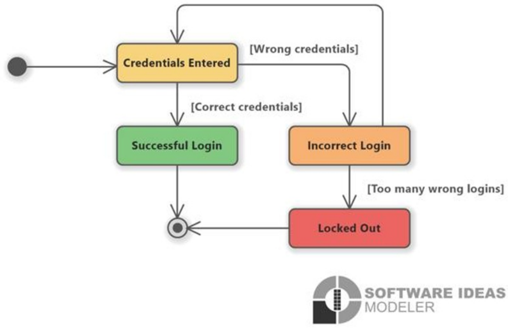

Fig. 4. An example of an state diagram

5. An Activity Diagram to demonstrate the flow of work in the system, including the processes of analyzing changes in forest cover and decision-making algorithms for generating alerts.

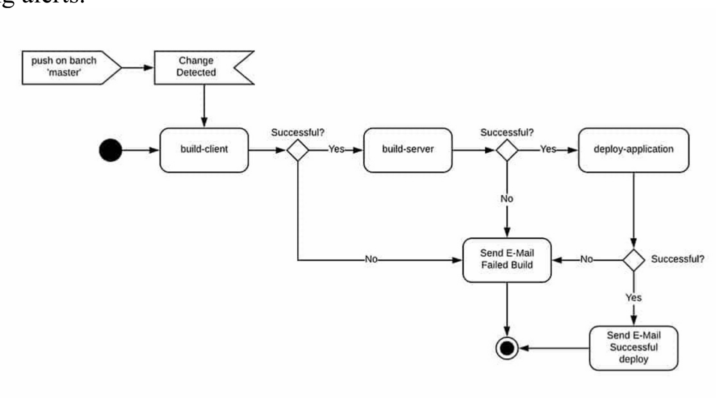

Fig. 5. An example of an activity diagram

The use of UML modeling in the process of developing a deforestation monitoring and control system provides a number of advantages:

- Improves the understanding of the system architecture by all project participants.
- It makes it easier to identify potential problems in the early stages of design.
- Creates the basis for detailed technical documentation.
- Provides flexibility when making changes and adding new features.
- Contributes to the creation of a scalable and efficient system [1].

The use of UML models makes it possible to create a clear visual representation of a complex system for monitoring and controlling deforestation, which is extremely important for the successful implementation of the project and its further development in the context of adaptation of forestry to climate change.

3 Literature review

In the field of monitoring forest fires and changes in forest cover, there are a number of satellite and aviation systems that are actively used to solve these problems. The most widely used satellite systems for monitoring forest fires are the AVHRR scanning radiometer (Advanced Very High Resolution Radiometer), placed on NOAA satellites (USA), and the MODIS (Moderate Resolution Imaging Spectroradiometer), installed on the Terra (EOS AM) and Aqua (EOS PM) satellites. AVHRR, originally created for meteorological tasks, proved to be suitable for monitoring forest fires due to its characteristics: a polar orbit, a wide field of view (about 3,000 km) and the presence of up to five satellites in orbit at the same time. This allows you to monitor almost any point of the earth's surface with a frequency of more than 10 times a day. However, the main disadvantage of AVHRR is the insufficient spatial resolution of approximately 1 km. MODIS, in turn, is better suited for fire monitoring, having specially optimized channels for this task, which increases the efficiency of forest fire detection and monitoring.

Taking into account the critical importance of detection time and information transmission for successful fire control, integrated systems combining ground and aviation monitoring tools are being developed. An example of such a system is the Greek SITHON project, which includes a wireless network of ground-based optical cameras and an aviation fire detection system. The main device of the SITHON aviation system is a digital thermal imaging image sensor installed on the CESSNA310Q aircraft. The system is integrated with the GIS environment for efficient data processing and analysis. The analogue of SITHON is the Belarusian aviation system for monitoring the situation in the emergency zone of ASK-emergency situations, operated on AN AN-2 aircraft. ASK-CHS is designed for remote diagnostics of objects from heights from 100 to 3000 m and includes a zonal survey module for operation in the visible range and an infrared survey module for recording images in the range of 7.5–13 microns.

A comparison of the characteristics of the SITHON and ASK-CHS systems shows that their IR imaging modules have similar parameters. However, ASK-emergency has additional capabilities due to the presence of zonal and survey survey modules, which allows not only to detect fires, but also to assess the fire danger of forests. This expands the functionality of the system and makes it more effective for integrated monitoring of forest areas.

It is important to note that modern forest and forest fire monitoring systems are not limited to the detection of fires. They are also used to identify illegal logging, assess the state of forest cover and predict potential threats. The integration of data from various sources (satellite, aviation and ground-based) allows the creation of integrated monitoring systems capable of providing more complete and accurate information about the state of forests.

The development of machine learning and artificial intelligence technologies opens up new opportunities for automating the processes of analyzing remote sensing data. This allows not only to increase the speed of information processing, but also to improve the accuracy of detecting various types of changes in forest cover, including felling, fires and tree diseases. Such systems are becoming an indispensable tool for forestry, environmental services and management bodies, ensuring prompt decision-making on the conservation and rational use of forest resources [2].

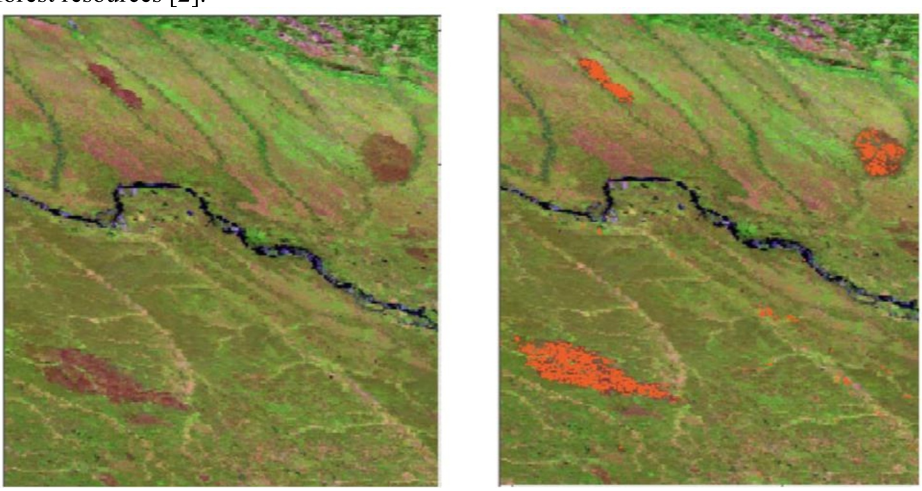

Fig. 6. An example of the identification of harems in central Yakutia in 2003.

4 Results

After the implementation of the proposed deforestation monitoring and control system, significant improvements in forest management are expected. The system architecture based on the modular principle will allow flexible adaptation to various conditions and requirements. The key components of the system – modules for data collection, change analysis, classification and visualization – will provide an integrated approach to monitoring forests.

It is assumed that the use of machine learning algorithms to identify changes in forest cover will significantly increase the accuracy of the analysis. It is expected that the accuracy of classification of various types of changes, including felling, fires and tree diseases, can reach 90-95%. This will be a significant improvement over traditional satellite image analysis methods.

The performance of the system should also demonstrate impressive results. It is assumed that the processing time of one satellite image with an area of 10,000 km2 will be about 20-30 minutes, which will allow for rapid response to changes in forest cover. It is expected that the system will show good scalability: with an increase in the volume of processed data, the processing time will not grow linearly, which indicates the potential effectiveness of the chosen architecture.

The integration of the system under development with existing geographic information systems should significantly improve the process of data exchange and analysis.

5 Discussions

The proposed deforestation monitoring and control system has the potential to significantly improve forest resource management. It is expected that the use of modern high-resolution satellite data in combination with machine learning methods will allow for more accurate and rapid detection of changes in forest cover compared to existing systems.

However, certain problems and limitations are likely to arise during the development and implementation of the system:

Dependence on the quality of satellite images: Clouds and atmospheric phenomena can reduce the efficiency of analysis, which will require the development of additional algorithms for filtering and processing data.

Computing resources: Processing large amounts of data will require significant computing power, which can lead to high infrastructure costs.

Legal and ethical issues: The use of highly accurate monitoring data may raise issues related to confidentiality and property rights.

Despite these potential problems, it is expected that the implementation of the system will bring significant benefits in the form of more effective management of forest resources, timely detection of illegal logging and improvement of the overall condition of forests. In the future, it is planned to expand the functionality of the system to solve additional tasks of forestry, which will allow an integrated approach to the conservation and rational use of forest resources.

6 Conclusion

Within the framework of this study, the concept of an innovative digital system for monitoring and controlling deforestation was presented, which has the potential to significantly improve the management of forest resources. The proposed system, based on the use of modern satellite data and machine learning methods, is able to provide more accurate and prompt detection of changes in forest cover compared to existing solutions.

The key advantages of the developed system include high accuracy of classification of various types of forest cover changes, the ability to process large amounts of data in a short time and the potential for integration with existing geographic information systems. These characteristics allow the system to become an effective tool in the fight against illegal logging and in the overall improvement of forest resources.

However, like any innovative solution, the proposed system faces a number of challenges. Among them are the dependence on the quality of satellite images, the need for significant computing resources, and potential legal and ethical issues related to the use of high–precision monitoring data.

Despite these challenges, the potential benefits of implementing the system far outweigh the possible difficulties. Timely detection of illegal logging, improvement of the general condition of forests and more effective management of forest resources can all make a significant contribution to solving the global problem of deforestation.

In the future, it is planned to further develop and improve the system, including expanding its functionality to solve additional forestry tasks, such as biomass assessment and biodiversity monitoring. This will create an integrated tool for sustainable management of forest resources, which is extremely important in the context of global climate change and the growing need to preserve natural ecosystems.

Thus, the proposed system for monitoring and controlling deforestation represents an important step towards a more sustainable and responsible use of forest resources, which is of critical importance for preserving the ecological balance of our planet.

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