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Jury Member Report – Doctor of Philosophy thesis.

Name of Candidate: Svetlana Illarionova

PhD Program: Computational and Data Science and Engineering

Title of Thesis: Deep learning for remote sensing of environment and land cover analysis

Supervisor: Professor Ivan Oseledets

Name of the Reviewer: Professor Artem Nikonorov

I confirm the absence of any conflict of interest	**Date: 09-01-2023**

The purpose of this report is to obtain an independent review from the members of PhD defense Jury before the thesis defense. The members of PhD defense Jury are asked to submit signed copy of the report at least 30 days prior the thesis defense. The Reviewers are asked to bring a copy of the completed report to the thesis defense and to discuss the contents of each report with each other before the thesis defense.

If the reviewers have any queries about the thesis which they wish to raise in advance, please contact the Chair of the Jury.

Reviewer's Report

Reviewers report should contain the following items:

- Brief evaluation of the thesis quality and overall structure of the dissertation.
- The relevance of the topic of dissertation work to its actual content
- The relevance of the methods used in the dissertation
- The scientific significance of the results obtained and their compliance with the international level and current state of the art
- The relevance of the obtained results to applications (if applicable)
- The quality of publications

The summary of issues to be addressed before/during the thesis defense

Brief evaluation of the thesis quality and overall structure of the dissertation.

The thesis consists of several studies and aims at developing robust and efficient approaches for environmental analysis, namely vegetation cover properties estimation using satellite data. The Introduction section sets the main objectives of the dissertation. It is followed by Literature review and 6 chapters with the main body of the work.

The first chapter presents the current state of the research on computer vision methods for forestry tasks. It discusses the most relevant remote sensing data sources, commonly used machine learning algorithms, and recent challenges such as lack of labelled data, environmental diversity, remote sensing data expensiveness.

The second chapter is devoted to object-based augmentation technique that was proposed for better generalization in remote sensing tasks. It allows one to achieve better results in such tasks as tree map creation using high resolution satellite data. It reduces requirement for labelled data and shows high performance in various geographical regions.

The third section presents an approach for dominant forest species estimation using multispectral satellite data. The proposed method involves a hierarchical classification approach that allows solving the forest species segmentation task sequentially (by splitting into forested and unforested regions, conifer and deciduous areas, and the target tree classes finally). It leads to higher and more balanced results. Also, the importance of auxiliary data such as canopy height has been successfully studied.

In the next section, a weakly supervised learning approach was adapted to adjust forest species classification. The proposed method takes into account the specificity of forest inventory data, namely, for each individual stand the percentage of each species is known, but spatial distribution is unknown. Therefore, a custom-loss function was proposed to reflect homogeneity of individual forest stands.

The next section presents an approach for near-infrared (NIR) satellite band generation. It has been shown that artificially generated data is useful for particular remote sensing tasks. A generative adversarial network (GAN) was applied to generate a NIR band based on RGB bands. It does not require labelled data and the generated NIR can further enrich RGB bands in cases where NIR is not available or highly expensive for high-resolution satellite data.

In the next section, another useful auxiliary data is considered. An approach for canopy height estimation is proposed and verified. The proposed approach performs compatible results with LiDAR measurements and adjusts forest species classification using convolutional neural networks.

In the last section, a novel augmentation approach for satellite multispectral data is proposed. It aims at adjusting neural-network robustness through different environmental conditions for remote sensing data (observation date, geographical location). The approach considers a set of summer satellite images obtained in different dates but for the same area. The augmented image consists of multispectral bands from different images that improves dataset diversity.

The relevance of the topic of dissertation work to its actual content

In the dissertation, an important topic of vegetation landcover monitoring is presented. The work addresses such challenges as data availability, forestry tasks specificity, forest properties estimation.

The relevance of the methods used in the dissertation

The state-of-the-art computer vision methods are used in the dissertation such as convolutional neural networks (CNNs) and generative adversarial networks (GANs). Although computer vision tasks are considered in the thesis, proposed approaches are adapted to meet demands of remote sensing and forestry tasks.

The scientific significance of the results obtained and their compliance with the international level and current state of the art

The obtained results are promising for large-scale predictions of vegetation properties with satellite data. The presented study is important for remote sensing applications in environmental research and can be extended to various related tasks.

The relevance of the obtained results to applications (if applicable)

Some of the proposed approaches for environmental study are applied in Mapflow.ai service and are publicly available for forested areas monitoring through satellite data. The described methods can be further used in various applications for robust estimation of environmental characteristics.

The quality of publications

The dissertation is based on publications in high-quality scientific journals and international conferences that cover both computer vision and environmental study topics. It includes IEEE Access (Q1), Remote sensing (Q1), IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing (Q1).

The summary of issues to be addressed during the thesis defense is the following.

1. Section 3.2.4, in your object-based augmentation technique for trees, which algorithm do you use for shadow direction estimation, do you use the information about the Sun position or estimation of the shadows in neighbor trees?
2. Section 4.2.3 – more details on Satellite data are needed here: which spectral bands were used, what normalization procedures were done, e.g. what type of atmospheric correction procedures was used. Same for the section 8.2.2.
3. Section 4.5.3 – more details on CNN architecture recommendation are needed, especially if "Both the WorldView and Sentinel studies show that the correct architecture for each task can adjust classification quality significantly."
4. MAE and RMSE metrics used for estimating the NIR prediction quality in table 7.1 are a bit hard to interpret, so it is interesting to additionally compute something like PSNR.
5. It also interesting to show how the NIR prediction will deal with any hard cases, e.g. for case where plastic objects mimic to vegetation.
6. In Section 8 and other sections, how do you deal with clouds in remote sensing data?
7. In Section 8, which atmospheric correction model do you use for Sentinel data, and what about the relation of this model with your augmentation technique.

Provisional Recommendation
☑ *I recommend that the candidate should defend the thesis by means of a formal thesis defense*
☐ *I recommend that the candidate should defend the thesis by means of a formal thesis defense only after appropriate changes would be introduced in candidate's thesis according to the recommendations of the present report*
☐ *The thesis is not acceptable and I recommend that the candidate be exempt from the formal thesis defense*

Prof. Artem Nikonorov 09.01.23