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REMOTE SENSING DATA FROM SPACE FOR ROAD IMAGE RECOGNITION IN THE FORESTRY

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Paper presents an overview of history and current research state on the use of remote sensing data from space to recognize roads for the regional projects in the forestry. We reviewed the principles of road detection on the optical satellite imagery. Group of direct recognition features used in combinations such as brightness and texture, geometry and brightness. Three research directions with examples were identified: visual roads recognition, use of special software and libraries for developers, and neural networks. For the road network detection we have described methods and software, type and spatial resolution of imagery. Road image recognition based on the optical survey from the open and commercial sources, machine learning methods and neural networks. Up-to-date tasks of road recognition are the following: evaluation of road surface condition, modeling of existing roads location, designing and building new roads, roads seasonality. A functional summary of MapFlow plugin for road recognition in Open Source QGIS is given. Paper is a part of regional forestry transport modeling project to access the forest fires and forest resources by ground means.

Keywords: *remote sensing data from space, road network, image recognition, forestry, neural networks, convolutional neural networks, Open Source QGIS, plugins, MapFlow*

Recognition of road network on the satellite imagery is a challenging task both in visual and automated image detection due to the number of difficulties, for instance, combining geometrical and brightness characteristics. We continue research on the modeling the ground movement of firefighters and logging vehicles reaching forest fires and forest resources at the regional level and undertake analysis of scientific papers on the use of data from space to detect road network.

The technology to create access routes, which was developed at the Laboratory of Forest Ecosystems Monitoring of the Center for Forest Ecology and Productivity, the Russian Academy of Sciences (CEPF RAS) collects datasets on routes for an arbitrary period of time, including the fire season (Podolskaia et al., 2020). Up-to-date data on the public and special access roads (forest roads, winter roads) are required to get the correct results in the database.

There is a need for methods and technologies for recognizing and updating data over a road network. Researchers are often focused on how to define presence and location of roads, which are missing in the global and regional datasets. The main source of Open data for the regional roads of entire Russian territory and the world is the vector layers of the Open Street Map project (OSM, https://www.openstreetmap.org/); an example is given in the paper (Podolskaia et al., 2020). Links between OSM data and object recognition at different spatial localization (Muhametshin, Samsonov, 2022), in particular, roads, were studied in, for example (Nachmany, Alemohammad, 2019; Oehmcke et al., 2019; Ayala et al., 2021). The topic of image recognition as a hybrid of Information Technology and Data Science attracts a lot of attention, as evidenced by the review of K. Bhil with colleagues (Bhil et al., 2022).

Infrastructure road projects are getting more complex, require up-to-date and detailed survey data. Present research is devoted to one of the aspects of road image definition and updates — recognition of road geometry on the optical satellite imagery. A separate topic is the use of shooting from unmanned autonomous vehicle (UAV), which is currently developing in Russia in its technical and legal aspects.

Goal of the paper is to overview Russian and foreign scientific publications on the recognition of linear objects of road network infrastructure using remote sensing data obtained from space and then to identify the possibilities for recognizing roads for the regional forestry transport projects. To achieve this goal, it is necessary to solve the following tasks: to characterize the current state of art for the road recognition from space images based on the results from scientific papers for regional projects, to show the features of road recognition in the forestry and to give examples of Open Source tools.

1. ROADS RECOGNITION ON THE SPACE IMAGERY: CURRENT STATE OF ART

Satellite imagery is widely implemented for the different types of transport projects. Road as part of a complex infrastructure facility or project (road construction, oil and gas) is detected taking into account the objects of its surroundings. Space surveys are used in the engineering surveys and design of railways and highways (Bekturov, 2015; Filatova et al., 2017; Andreeva et al., 2019), defining the structure of road network (Mikheeva, Fedoseev, 2016). Roads are one of the elements of general geographic map content, their recognition related to the generalization of a linear object on the imagery (Podolskaia, 2005). For the railways at scale of imagery from 1:25 000 and larger, it is possible to decrypt two rails at a constant distance from each other using border identification tools in the

MATLAB system (Zhurkin, Badyshev, 2014). Papers (Dolgopolov et al., 2019; Dolgopolov, 2020) present the analysis of pipeline decryption and accompanying linear infrastructure for the oil and gas industry.

Space images of different types remain the main data source for identifying roads at the regional and local levels. For the scientific research on the transport modeling, it is necessary to understand the possibilities of modern and, most importantly, accessible satellite imagery of different types and resolutions. Non-commercial optical range shooting (Landsat and Sentinel-2 spacecrafts) remains one of the main sources of image analysis in scientific research and also used to recognize roads of different classes. For example, recognition of unpaved roads: papers on narrow dirt roads in southwestern Brazil (Gomes et al., 2015) and unofficial rural roads in the Brazilian Amazon (Botelho et al., 2022) use this satellite optical survey.

Combination of the optical multi-zone and hyperspectral images helps to define changes in the transport network configuration, for which a combined technology of object-oriented analysis for a set of images with cluster and contour processing methods is used (Mikheeva, Fedoseev, 2016). Radar imagery (Henry et al., 2018; Wei et al., 2021) are used less frequently due to the need of preprocessing compared to the optical survey, which is more affordable in cost, but more dependent on meteorological conditions (cloud cover).

In order to characterize modern road recognition, we describe principles for the linear objects. Firstly, roads are extended objects with geometric (shape, size) and brightness (tone, brightness level, color, spectral image) features (Mikheev, Fedoseev, 2016) changing within the image. The geometry of the road in regional projects refers to its shape and size (width), skeleton of the road network geometry is their centerline. An example of joint use of geometric and brightness features is given in the paper (Fedoseev et al., 2018). Secondly, structural features (texture, structure, pattern) and combinations of luminance and structural features are also used for detection, for example, a spectral-texture segmentation algorithm in the paper (Pestunov, Rylov, 2012).

Indirect detection features of the road network are natural (to show the relationship of roads with natural objects), anthropogenic (to identify the functions of roads as objects for communication between settlements, location in the socio-economic infrastructure of the territory), as well as natural and anthropogenic (to indicate the links between landscape and transport development).

In addition to geometric, brightness and structural features, modern research distinguishes topological (connectivity) and functional (use) attributes (Botelho et al., 2022) for the automated road recognition model. To detect the road network, as noted by a number of Russian authors (Miroshnichenko et al., 2013; Tusikova, Vikhtenko, 2019; Ignat'ev et al., 2022), there is a need to select images with a set of key characteristics. They are: significant road length within the image, constant road width, and uniform distribution of the road image's brightness within the image and road surface clarity. Thus, the main stage of satellite data processing is an image segmentation into thematically homogeneous areas, followed by transformation into a vector format.

Historically road recognition has been started from the example of settlements streets when the satellite imagery of spatial resolution of about several meters were made available (Guindon, 1998). A large review on the automatic road recognition for geoinformatics has been made in the paper (Mena, 2003). It describes the main tasks of recognition: segmentation, vectorization, evaluation and optimization, semantic neural networks, as well as methods and tools of fuzzy logic. This research dated back to 2003 should be continued and updated with a description of present recognition methods and examples of neural networks.

Preparation of image fragments at the beginning of 2000 laid the groundwork for modern road recognition with neural networks method, which is one of the Deep Learning classification algorithms, establishing weight of importance to various regions and objects on the image for the subsequent iterative recognition. Among neural networks for linear objects of the road network, we used convolutional neural networks (CNN) and regional neural networks Region-Based-CNN (RCNN). The decisive advantage of choosing a convolutional network is a shorter, in comparison with other classification algorithms, processing time and far fewer computing resources for images preprocessing (Skripachev et al., 2022). Currently, the best results in semantic image segmentation for road recognition are obtained using the fully connected convolutional neural network Fully CNN, which is a set of connected layers, each neuron of one layer is associated with each neuron of the other one.

An example of RCNN use in Russian publications is Mask-RCNN (Tusikova, Vikhtenko, 2019). Its convolutional principle combins the values of adjacent pixels and detects the most generalized features for the road. Presently quality limitations of network recognition depend on the size of training sample and detail of its annotation (preliminary segmentation). Significant set of data (numbering about thousands of images) is required for the high-quality neural network training. Variants could be found in the ready-made annotated sets; examples of open access are just beginning to appear. We can use space image annotation to automate objects detection, which is assigning a signature or label using keywords.

Researchers attribute the identification of road surface type (Tormozov et al., 2020) and monitoring road technical condition (Chelnokov et al., 2021) as separate tasks of road recognition. A number of roadway identification papers use hyperspectral images and machine recognition methods, noting the need for ultra-high resolution data to determine the road accident ratio (Mikheeva, Fedoseev, 2014; Fedoseev et al., 2016|, 2018). Recent papers published some scientific results of GIS infrastructure project “ITSGIS” (http://itsgis.ru/).

Evolution and current capabilities of road recognition methods and technologies based on the data from space are shown in the Table 1. It groups the characteristics of Russian and foreign papers into the development stages to recognize roads on space images in regional projects. Papers could be grouped into 3 categories, namely: visual detection, use of special software and libraries, and then neural networks. As Table 1 shows, there was a transition from manual expert visual decryption to automated recognition by neural networks based on the expert experience and training sets with a high results accuracy.

The prerequisites for such transitions were the well-known capabilities of information technologies: speed and volume of data processing, especially high-resolution satellite data processing. Advantages of neural network recognition include the speed and availability of image processing; disadvantage is the time spent for the segmented image preparation to be a training sample.

Case studies cover different regions of Russia and the world, used mostly optical imagery. Significant research part dedicated to the use of datasets and neural networks for road recognition is presented by English-language publications. Each block of the Table contains years of publication, which helps to show the historical development of methods and technologies to detect roads on the images stating from the imagery of 1-meter-resolution. The most popular as a Deep Learning library in the studied researches is Keras [1]. One of the most used neural network ResNet101 (https://keras.io/api/applications/resnet/) should be mentioned among the modern examples.

2. ROADS RECOGNITION IN THE FORESTRY

Research experience presented in the Table 1 is useful to recognize a road network on the space images for the forestry transport modeling. Updating of forest road geometry is important in the forestry because forest roads make direct access to the paved roads. There are very few Russian publications on the forest road networks, namely (Orlov, 2006; Shoshina, 2013). First paper is devoted to the connection of road attribute features with pictorial segments and network topological description. Strategy to detect a road depends on its class. About 15 options were mentioned for the roads detection, combining properties of road segments and its location characteristics. Second research describes a system for monitoring forest roads, indicating their main definition signs. This publication focuses on the technical condition of forest roads and possible technologies for detecting defects depending on the season. Tasks of roads

[1] Open Source Python-based library which is aimed to interact with neural networks

Table 1. Roads recognition on space images at regional level

Recognition methods and key words	**Satellite and spatial resolution**	**Software/ library**	**Key area**	**Reference**
Group 1 — visual detection				
Visual recognition of roads and railways	RapidEye (5 m)		Sparsely populated areas of Western Siberia	Kobzeva, 2010
Roads identification and monitoring of its condition by season based on the space imagery with field studies validation	Formosat-2, Eros A/B, Ikonos-2, QuickBird, Ресурс (1–10 m)		Arkhangelsk region, Russia	Shoshina, 2013
Group 2 — special software and libraries				
Automatic recognition of road pavement (bitumen, concrete, gravel, soil); road network segmentation	Spot panchromatic (10 m)	IMAVISION image analysis system	Canada	Maillard, Cavayas, 1989
Automatic road retrieval, vectorization, connection of road segments	Quickbird, Ikonos, Spot, Aster, Landsat-ETM (2,4–30 m)	PCI Geomatica	Turkey	Gecen, Sarp, 2008
Clustering of hyperspectral data for the transport infrastructure facilities monitoring	EO-1, Hyperion (30 m)	ITSGIS	Samara region, Russia	Mikheeva, Fedoseev, 2014
Deep learning, segmentation, roads and infrastructure detection	Sentinel 2 (10 m)	Python (3.6), PyTorch (1.0)	Denmark	Oehmcke et al., 2019
Segmentation, object analysis of images, mathematical morphology	Ikonos-2 (4 m)	ENVI	Italy	Barrile et al., 2020
Image segmentation, mathematical morphology	WorldView-3, (0,3 m panchromatic, 1.24 m — multispectral)	MATLAB	USA	Satyanarayana et al., 2020
Group 3 — neural networks				
Deep learning, semantic segmentation, convolutional neural network, central line algorithm, user simplification algorithm	WorldView-3, SkySat, Planet Dove, Sentinel-2 (1–10 m)	U-Net based network. Keras Open Source deep learning library	Europe, Africa, Central America	Riedl et al., 2019
Fully convolutional neural network (FCN). Data increment, deconvolution, and conditional random field	IKonos, QuickBird, WorldView and GeoEye (approx. 1 m)	AlexNet, VGG-Net. Keras Open Source deep learning library	USA	Zegeye, 2020
Connectivity network (CoANet) to jointly explore segmentation and pairwise dependencies	SpaceNet and DeepGlobe datasets (0,3–0,5 m)	ResNet-101 pre-trained on ImageNet	Different areas in the world	Mei et al., 2021

detection are to identify the road presence and pavement type, to assess the road state and to identify the segments that require reparation. For the foreign part of the analysis we note a paper (Caliskan, Sevim, 2022), which gives recommendations on the deep learning models for semantic segmentation of forest roads like neural networks ResNet-50 and InceptionResNet-V2.

Forestry peculiarities include the seasonality of road use. In order to model ground access in the forestry, satellite imagery of different year periods are needed, namely: off-season, summer and winter (Shoshina, 2013). Throughout every season of the year, part of the roads will be open; in winter, in addition to public roads, winter roads begin to operate in certain regions; in summer and in the off-season, part of the roads may be inaccessible due to the surface state (Podolskaia, 2022). So, access routes to reach forest resources and forest fires will differ seasonally.

Thus, the current tasks of roads detection in the forestry include assessing their coverage state, modeling the location of existing and designed roads, as well as taking into account the seasonality of road operation.

3. MAPFLOW PLUGIN FOR OPEN SOURCE QGIS

A practical example of an Open Source road recognition tool in the forestry transport projects is the QGIS MapFlow plugin. Nowadays it is one of the image recognition plugins for the roads, which is accessible from the library of Open geoinformation tools (https://plugins.qgis.org/) developed and regularly supported with new versions by GeoAlert (https://geoalert.io/). MapFlow currently uses high spatial resolution optical survey as raw data. Raster road mask is prepared from the image, then it is converted into a set of road centerlines and vectorized to be in GeoJSON format; pavement type and road boundaries (https://geoalert.medium.com/mapflow-ai-new-roads-model-e989557cef26) are also determined. The current version of the plugin dates back to April 2023 (https://plugins.qgis.org/plugins/mapflow/). Plugin has been loaded into the repository since July 2021 and is used for the RuMap platform (http://www.digimap.ru/products) of Geocentre Consulting.

CONCLUSION

Paper provides an overview of available scientific publications on the use of remote sensing data from space for road recognition highlighting features for forestry transport modeling. For implementation in the forestry transport projects we have identified the following research areas.

Firstly, basics of automated road recognition are applied. Roads are being recognized on the images of open and commercial sources, imagery of spatial resolution starting from centimeters to meters are used. For the roads direct detection features are preferably used; they can be better automated in comparison with indirect ones. Researchers over the past 20 years have switched from manual visual decryption of linear objects of road network to the use of deep learning methods and neural networks. Significant time and technical efforts are still being invested in the preparation of training datasets for the neural network, their quality significantly determines recognition result. Thus, the use of artificial intelligence (AI) methods and technologies is an obvious, actively and constantly developing research question.

Secondly, thematic forestry tasks using data from space and AI remain the following: assessment of road state, identification of its accident rate, as well as design modeling and construction of new roads. To detect and to monitor the state of forest roads in the Russian regions it is advisable to shoot high and ultra-high imagery, which can be done using UAV. This shooting technology is of significant interest due to the ultra high spatial resolution (about centimeters), its ability to make the preparation process relatively quicker compare to the shooting from satellites and availability of software processing tools.

As examples of positive forestry outputs, we note several papers (Gulci et al., 2017; Akay, Tas, 2018; Turk et al., 2022). Currently it is difficult to assess the effectiveness of UAVs for road recognition against the use of space images for regional projects. The efficiency assessment will depend on the geographical location of key area, presence and geometrical complexity of road network, terrain, infrastructure and other parameters. The question requires further research and experience gathering from different countries and regions. Due to the present complications to obtain high and ultra-high spatial resolution space imagery in Russia, local UAV surveys even taking into account management, fieldwork and labor costs may be the only option for obtaining data for regular monitoring of road condition.

For the years to come the data obtained from UAVs will be one of the sources used to update the road network image in various GIS projects, including forestry. Definitely, shooting from space and using UAVs will continue to be the two main data sources for roads detection. For various road projects and forestry there are some common patterns like use of mostly accessible open data Landsat and Sentinel. There are still few scientific publications aimed to recognize forest roads on the satellite imagery.

Number of references shows that for the road recognition the most informative and currently used features are direct decryption features (geometric, brightness), then direct texture features applied. Research of last decade implements a combination of direct features, like brightness and texture, geometry and brightness. Papers' analysis states that tasks of using satellite imagery to recognize road images can be divided into several groups. First of all, there is a need for any imagery in the absence of updated data on the road network, and then the lack of an open access accurate coordinate reference of the linear road infrastructure and finally a need to monitor road coverage for accidents and to carry out subsequent economic assessments.

Regional forestry projects are complex, large-scale and, therefore, costly from the resources point of view. Main technology for their implementation for the road recognition part will remain neural networks, which are constantly improving in their quality and data volume; neural networks have a tendency of becoming open products that collect recognition examples of linear, point and polygon type objects.

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ИСПОЛЬЗОВАНИЕ ДАННЫХ ДИСТАНЦИОННОГО ЗОНДИРОВАНИЯ ЗЕМЛИ ИЗ КОСМОСА ДЛЯ РАСПОЗНАВАНИЯ ИЗОБРАЖЕНИЯ ДОРОГ В ЛЕСНОМ ХОЗЯЙСТВЕ

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В статье представлен обзор развития и текущего состояния научных исследований по использованию данных дистанционного зондирования Земли (ДЗЗ) из космоса для распознавания изображения дорог в региональных лесохозяйственных проектах. Дана характеристика принципам выделения линейных объектов дорожной инфраструктуры, отмечено, что прямые дешифровочные признаки используются в таких сочетаниях, как яркостные и текстурные, геометрические и яркостные. Выделено три направления работ с примерами: визуальное дешифрирование, использование специального программного обеспечения и библиотек разработки, а также применение нейросетей. Приведено описание методов и программных средств распознавания дорожной сети, типов и пространственного разрешения необходимой космической съемки. В обзоре показано, что основой распознавания изображения дорог являются данные оптической съемки открытых и коммерческих источников, методы машинного обучения и нейросети. Актуальными задачами распознавания дорог для лесного хозяйства являются: оценка состояния покрытия дороги, моделирование расположения существующих, проектирование и строительство новых дорог, учет сезонности. Представлено описание функциональности плагина MapFlow как инструмента по распознаванию дорог для Open Source QGIS. Статья является частью разработок по региональному лесному транспортному моделированию наземного доступа к лесным пожарам и ресурсам леса.

Ключевые слова: *данные ДЗЗ из космоса, дорожная сеть, распознавание объектов, лесное хозяйство, нейросеть, сверточная нейросеть, Open Source QGIS, плагины, MapFlow*

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