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---Turning Data into Insights---

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Edited by P. Soille, S. Loekken, and S. Albani

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Preface

Big Data from Space refers to the massive spatio-temporal Earth and Space observation data collected by a variety of sensors - ranging from ground based to space-borne - and the synergy with data coming from other sources and communities. This domain is currently facing sharp developments with numerous new initiatives and breakthroughs from intelligent sensors' networks to data science application. These developments are empowering new approaches and applications in various and diverse domains influencing life on earth and societal aspects, from sensing cities, monitoring human settlements and urban areas to climate change and security.

The main objectives of the BiDS'19 Conference are:

- Focus on new paradigms of data intelligence addressing the entire value chain: data processing to extract information, the information analysis to gather knowledge, and knowledge transformation in value;
- Maximise the uptake and impact of multi-source space data;
- Promote the use of platforms and analytical methods to maximise the value extracted for scientific exploration and discovery, societal benefits, commercial exploitation and operational applications;
- Bring together major European actors, including research, industry, institutions, and users, to strengthen the communication and transfer of requirements, methods and technologies, and to reinforce an interdisciplinary approach;
- Promote research and applications in innovative/disruptive data analysis methods;
- Advance the upscale of new solutions from research and innovation to operational use (e.g. for the security domain);
- Promote cross-fertilisation with similar works in other data intensive domains (e.g. high-energy physics, microbiology, social media, etc.).

The BiDS'19 Conference is co-organised by the European Space Agency (ESA), the Joint Research Centre (JRC) of the European Commission, and the European Union Satellite Centre (SatCen). It is hosted by the German Aerospace Center (DLR) in Munich, one of the key European cities with numerous activities focused on space and aerospace developments and applications.

These proceedings consist of a collection of 75 short papers accepted for oral or poster presentation at the conference as a result of the peer-review process by the conference programme committee. The papers are lined up around the topics matching the oral sessions as well as the poster session, also organised by topics.

This 4th edition of the Big Data from Space conference is directed towards 'Turning Data into Insights'. Indeed, while the first editions of the conference concentrated on technologies and platforms capable of sustaining the sharp increase of data streams originating from space sensors, the development of efficient and effective methodologies and algorithms capable of extracting insights from these data is gradually becoming the main challenge. In this context, artificial intelligence and machine learning techniques have started to play a key role as illustrated by numerous papers of this conference edition. Methodological developments are motivated by the pressing need to extract information on large areas and/or over long time series to better understand the dynamics of the processes that are shaping our planet and indeed our universe in the case of data collected by telescopes. The topic of analysis ready data has also emerged since the last edition and is closely linked with the development of new data cube representations. Big Data from Space is also introducing some new legal challenges and the need for further developments of standards and interoperable interfaces between the growing number of platforms hosting multi-petabyte scale data co-located with processing capabilities. All these topics as well as other generic key aspects of big data are mirrored in dedicated sections of these proceedings. They provide a snapshot of the current research activities, developments, and initiatives in Big Data from Space.

Further to the regular oral and poster contributions, the conference has been enriched by 5 enlightening invited keynote lectures addressing various big data topics of interest to Big Data from Space:

1. *Artificial Intelligence and Data Science in Earth Observation*
   by Xiaoxiang Zhu (DLR-IMF, Head of Department "EO Data Science")
2. *Mosaics in Big Data: Stratosphere, Apache Flink, and Beyond*
   by Volker Markl (Technical University Berlin, Data Analytics Lab & DFKI)
3. *Overview of JPL data science for Earth science*
   by Tomas Huang (NASA JPL, Computer Science for Data Intensive Applications)
4. *European Data Relay System Achievements and Capabilities*
   by Harald Hauschildt (European Space Agency, Telecom & Integrated Applications Dept.)
5. *Machine learning in Earth Observation data analysis*
   by Gustau Camps-Valls (Universitat de València, Dpt. Enginyeria Electrònica (DIE), Image Processing Laboratory (IPL))

Additional conference materials such as electronic version of the slides presented at the conference, including those regarding the opening session talks and keynote lectures, are available on the conference website: www.bigdatafromspace2019.org.

Great thanks goes to all authors and presenters of BiDS'19 as well as the numerous participants (over 600 registrations from more than 50 different countries). Together, they have ensured the success of the 2019 conference on Big Data from Space. Special thanks goes to the Programme Committee members and the additional reviewers for their thorough reviews and detailed comments that were taken into account by the authors when preparing the final version of their paper included in these proceedings.

This edition of the BiDS conference is deeply grateful to the German Aerospace Center (DLR) for its strong support in having BiDS'19 hosted in Munich.

Pierre Soille, Sveinung Loekken, and Sergio Albani

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HOW MANY ROADS? OBJECT SEGMENTATION ON SATELLITE IMAGERY IN A PRODUCTION ENVIRONMENT

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ABSTRACT

Developing automated information extraction methods is indispensable for handling the large amount of satellite imagery operated by governments and businesses around the world. Recent advances in the area of deep learning have successfully contributed to automating traditional object detection tasks. This work applies a well-known convolutional neural network (CNN) to extract roads from satellite images which are diverse in terms of spatial resolution, landscape, viewing angle, and other properties. We first conduct several experiments by training a U-Net based network on high-resolution satellite imagery of 11 regions in 3 continents. In a second step, we apply another network trained on thinned targets, followed by a centerline algorithm and a custom simplification algorithm to transform the results to a connected vector representation. In this paper, we propose a complete workflow for automated road extraction with a special focus on the applicability in a vector data production environment.

***Index Terms*—** Deep Learning, Semantic Segmentation, Remote Sensing, Convolutional Neural Network, Road Extraction

1. INTRODUCTION

Retrieving information from high-resolution satellite imagery is essential for a wide range of application fields, such as mobility, agriculture, and defense. A common approach to extract features is to manually segment or vectorize the images. This is a time-consuming task and requires a high level of expertise. Therefore this approach does not scale well to the drastically increasing amounts of satellite data available.

Most established approaches for automating object recognition tasks are limited to specific scenarios (e.g. land cover) or satellite specifications (e.g. resolutions), such as [9]. Due to these generalization limitations, they often fail to meet customer quality requirements.

Novel network architectures proposed in the field of deep learning, such as U-Nets [10], received particular attention for their performance in pixel-wise semantic segmentation and their generalization capabilities. They have been applied successfully to one-class segmentation tasks, such as road detection [1, 7], and multi-class segmentation tasks [3, 5], such as detection of vegetation, buildings, water bodies and so on.

The segmentation output is usually represented as a raster graphic. However, for many practical applications the output needs to be in a vector format. There are several methods to convert raster representations of line features, like roads or rivers, to vector representations and create simplified and connected graphs. For example, Haunert and Sester [2] present an automatic approach to create road centerlines using special characteristics of straight skeletonization algorithms. Máttyus et al. [6] suggest a shortest path algorithm to close missing connections in the extracted road graph.

While most research investigates single aspects of road detection with a major focus on algorithmic challenges [8], we explore the application of deep learning for road detection in geo-data production environments towards leveraging rapid-mapping applications like disaster mapping. For this, the models need to a) generalize well to different satellite scenes with different spatial resolutions, regions in the world, seasons, and so on and b) be efficient in terms of training and prediction time, and c) provide a vector data output for subsequent processing.

In this paper, we propose a workflow that is applicable in a geo-data production environment. We refer to road detection for demonstration purpose. In general, our approach can be applied to other domains to support different object segmentation tasks in satellite image analysis, like coniferous forest segmentation. Based on manually - and thus highly accurate - labeled satellite scenes taken from different regions in the world, our approach is highly generic in terms of different scenarios and satellite specifications. By using model ensemble methods and postprocessing steps, we can generate an accurate vector representation of the road network from satellite imagery, while taking into account the requirements of production environments.

2. DATA

For training, high-resolution satellite images with a spatial resolution of 1 m are used. So far, we selected 19 areas of interest (AOI) and labeled them manually with ArcGIS. The

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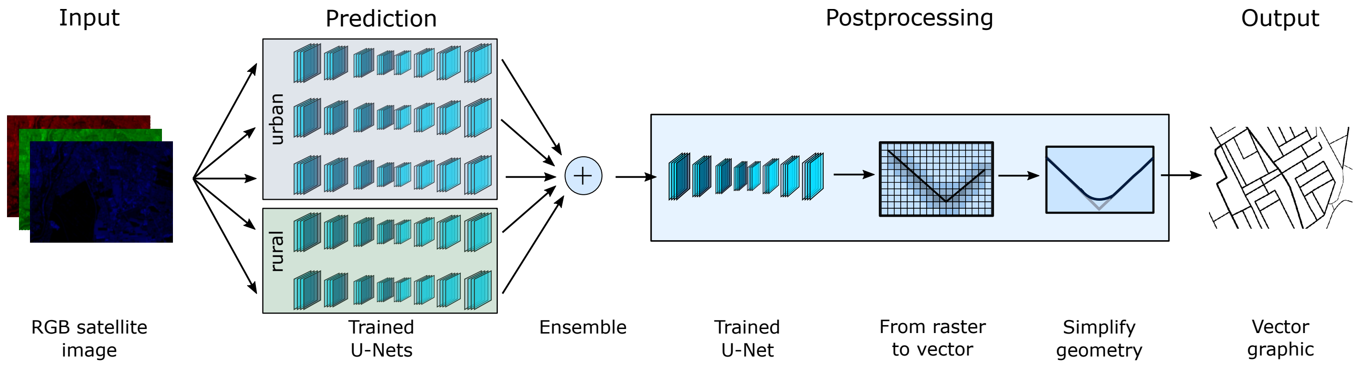

Fig. 1. Our proposed workflow to extract road vectors from satellite imagery in a production environment.

selected AOIs contain both rural and urban areas of 11 regions in 3 different continents (i.e. Europe, Africa, and Central America). In total, the imagery currently covers a surface of about 420 km^2.

To test the transferability of our workflow to other scenarios (e.g. seasons, climate zones) and sensor specifications (e.g. spatial and radiometric resolution, viewing angles), we use satellite imagery from various satellites, such as SkySat, Planet Dove, Sentinel-2 and others.

3. METHODOLOGY

Fig. 1 illustrates our proposed workflow, which we implemented in Keras. It consists of two phases: prediction and postprocessing. We use an input size of $(512, 512)$ with 3 channels (RGB). These input images are classified at pixel level as roads in the prediction phase. In the postprocessing phase, the conversion from raster to vector representation takes place in three steps. First, we use another U-Net to thin the detected roads and fill gaps in the road network. This is an important preparation for the second step, the conversion from raster data to centerlines, and eventually vector data. The third step is the simplification of the vector data.

For the prediction, we use the network architecture shown in Fig. 2, which is based on the U-Net architecture originally proposed by Ronneberger et al. [10]. The U-Net is an adaption of a fully convolutional network specifically designed to solve segmentation problems.

Our architecture consists of 3 downsampling blocks for encoding and 3 upsampling blocks for decoding. A downsampling block has 3 convolutional layers and a max pooling layer of size $(2, 2)$. Each convolution layer consists of a convolution, a batch normalization and a ReLu activation function. Conversely, an upsampling block has 3 convolutional layers and a transposed convolutional operation. The number of filters is increased after every block by a factor of two in the decoding part and decreased by a factor of two in the encoding part. For training we use an Adam optimizer with a loss function that is a convex combination of the cross-entropy and the negative logarithm of the Jaccard index as in [1], i.e.

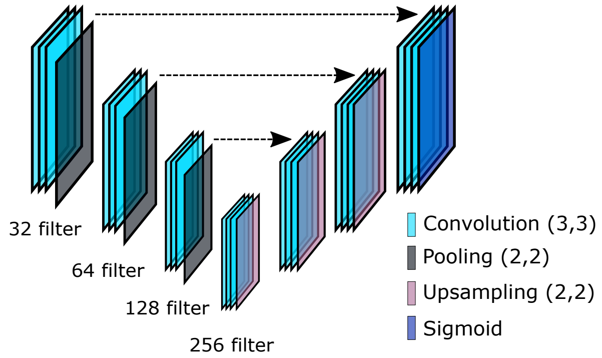

Fig. 2. The applied network architecture based on a fully connected U-Net. The amount of filters duplicates by each downsampling block.

$$L(X, \hat{X}) = \alpha H(X, \hat{X}) - (1 - \alpha) \log(J(X, \hat{X})),$$

where H is the binary cross-entropy and J is the Jaccard index.

For the prediction phase of our workflow, we have trained 3 models on images that contain mainly urban areas, while 2 models are trained on mainly rural-like regions. The images are clustered as ”rural” and ”urban” by the amount of road pixel in the target. Then, we average the predictions of these 5 models. The ensemble of these models allows an accurate segmentation in both rural and urban areas.

For the postprocessing, we apply another network of the same architecture which is trained using centerlines derived from vector data as labels and the predictions of the first network as features. We smooth these predictions by a filter and use it as input for the raster to vector conversion. Then, we convert the road polygons to their centerline. To fit quality requirements for road vector data, junctions are generalized and reconstructed with respect to topological and geometrical features. We finally simplify the road lines by removing unnecessary vertices within a specified distance.

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(a) Original satellite scene (b) Prediction (raster) (c) Postprocessing (vector) (d) Ground truth

Fig. 3. Intermediate outputs of the steps in our workflow.

4. RESULTS AND DISCUSSION

An example of intermediate and final outputs of our workflow is shown in Fig. 3. From left to right, it shows a satellite image with a spatial resolution of $1\,\mathrm{m}$ (a) on which a pixelwise object segmentation is applied by an ensemble of 5 models (b) and is then converted to the final vector output (c). For comparison, the manually created ground-truth vector is also displayed (d). Note that all satellite scenes shown and discussed in this section have not been included in the training.

We have used 4 GPUs for training. Based on our train set of roughly $420\,\mathrm{km}^2$ the training of 5 models took about $3\,\mathrm{h}$.

Even though the prediction in Fig. 3 (b) appears rather accurate, we face challenges in converting this raster graphic to vectors, as it contains small segments of false positives or false negatives. Therefore, postprocessing is necessary and essential to obtain a meaningful vector representations.

During development we noticed that commonly used metrics, such as the Jaccard index or F1 score, are not sufficient to describe the correctness of the output. As they measure the accuracy based on the raster graphic, they do not necessarily yield a good estimate of the quality of the road network as vectors. For example, those scores do not indicate if and how many small missing segments exist. Thus, they can not infer the connectedness of the vector graph which is an important graph property for the usability of the output.

In a production environment it is important that the objects can be segmented a) to high accuracy, b) as vector representations, and c) in a minimal amount of time. The big advantage of the type of networks we implement is that they can be adjusted to arbitrary size of input images. Hence, when using a sliding window approach for predicting large satellite scenes, one can tune the window size to best use the available hardware. This allows deployment of the models on systems with limited computational power and flexible distribution to scale with increasing demand. A prediction of a $20\,\mathrm{km}^2$ scene with a spatial resolution of $1\,\mathrm{m}$ takes $4\,\mathrm{min}$ using a NVIDIA GTX 1060 graphic card ($136\,\mathrm{min}$ using CPU only). Thus, the user can obtain a very good first impression of unknown regions already before further postprocessing steps. Fig. 4 shows a satellite image of Nigeria. The OpenStreetMap data is very sparse in this area, as shown in blue. However, our prediction, illustrated in pink, allows the user to quickly extract how many roads roughly exists in this scene.

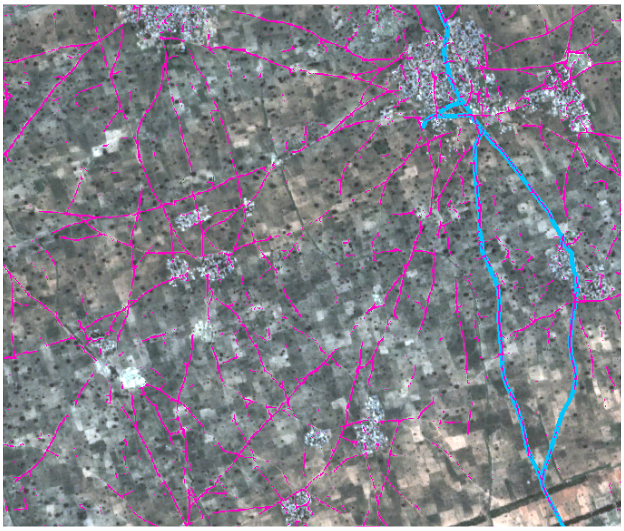

Fig. 4. Exemplary Planet Dove satellite image showing a region in Nigeria with a spatial resolution of $3\,\mathrm{m}$. The corresponding OpenStreetMap data is illustrated in blue. Our prediction is shown in pink, given an impression of how many roads truly exist in this region.

Moreover, our workflow can be applied to satellite imagery with various satellite specifications. Fig. 5 shows 4 satellite images of different regions. They vary in their spatial resolutions (from $1\,\mathrm{m}$ to $10\,\mathrm{m}$) and include both urban and rural areas. By the combination of prediction and postprocessing our workflow outputs connected vector representations for various satellite images. The final vector representations are illustrated in the second row on top of the corresponding satellite image. Thus, our workflow can be easily scaled for deployment in production as a part of automatic feature labeling systems for satellite imagery analysis.

5. CONCLUSION

Satellite imagery is highly important for a wide range of applications, such as topographic, land cover and disaster

Fig. 5. Exemplary results of our proposed workflow. 4 different satellite images are shown in the top row. The bottom images show the satellite scene with the vector output of our workflow (shown in pink).

mapping, as well as change detection. Due to the increasing amount of satellite data and rapid change of infrastructures, it becomes extremely relevant to automate the process of object segmentation. We propose a workflow that enables object segmentation in satellite imagery in a production environment. In particular, we demonstrate our workflow by applying it to road segmentation tasks. Our generic method comprises a prediction phase with several architectures followed by various postprocessing operations. This workflow allows an automatic extraction of a vector representation from a satellite scene.

We obtain high computational efficiency by using fully convolutional neural networks. The algorithm is able to predict a $20\,\mathrm{km}^2$ scene with a spatial resolution of $1\,\mathrm{m}$ within a few minutes on a middle class graphic card. This allows the user to obtain almost immediately a first impression of unknown regions. Another advantage is the diversity of our dataset. We train our models on both rural and urban areas to achieve a high transferability to regions not included in the training set, while obtaining comparable results.

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Abstract

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