УДК 004.08
doi:10.18720/SPBPU/2/id23-443

Machuca Mendoza Cristian Rodrigo, postgraduate student,
engineer of Information Technology Department,
Tomsk Polytechnic University,
Tomsk, Russia
kristianrodrigo1@tpu.ru

Markov Nikolai Grigorevich, DCs of engineering,
professor of Information Technology Department,
Tomsk Polytechnic University,
Tomsk, Russia
markovng@tpu.ru

RECONSTRUCTION OF SATELLITE IMAGES USING PARTIAL CONVOLUTIONAL NEURAL NETWORKS

Abstract. In the field of remote sensing, cloud removal from satellite imagery and reconstruction (inpainting) of areas under clouds remain as major challenges. This paper proposes a partial convolutional neural network-based algorithm for reconstructing multispectral satellite images with distant clouds. It is studied the performance of this neural network and the traditional U-Net neural network to solve the inpainting task.

Keywords: satellite images, U-Net, inpainting, semantic segmentation, sentinel-2.

Мачука Мендоса Кристиан Родриго, аспирант,
инженер Отделения информационных технологий,
Томский политехнический университет,
Томск, Россия
kristianrodrigo1@tpu.ru

Марков Николай Григорьевич, доктор технических наук,
профессор Отделения информационных технологий,
Томский политехнический университет,
Томск, Россия
markovng@tpu.ru

ВОССТАНОВЛЕНИЕ СПУТНИКОВЫХ ИЗОБРАЖЕНИЙ С ИСПОЛЬЗОВАНИЕМ ЧАСТИЧНЫХ СВЕРТОЧНЫХ НЕЙРОННЫХ СЕТЕЙ

Аннотация. В области дистанционного зондирования Земли удаление облаков со спутниковых изображений и восстановление областей под облаками являются актуальными задачами. В данной работе предлагается использование частичной сверточной нейронной сети для восстановления мультиспектральных спутниковых изображений с удаленными облаками. Исследована эффективность предложенной нейронной сети и традиционной сети U-Net при решении задачи восстановления.

Ключевые слова: спутниковые изображения, сеть U-Net, задача восстановления, семантическая сегментаця, sentinel-2.

Introduction. Satellite images provide highly useful and reliable information about the surface of the planet. They can be used in a big number of applications such as land cover classification, ecosystem monitoring, urban planning, etc. Taking into account that at all times, approximately 75% of the planet's surface is covered with clouds [1]. The availability of cloudless satellite images is a fundamental requirement for solving many applied remote sensing problems that are based on the spatio-temporal analysis of those images. Therefore, the task of removing clouds from satellite images is still relevant. Once clouds are removed, it is necessary to reconstruct the missing areas (areas under clouds) of the image by replacing the missing pixels with pixels predicted by extracting information from the surrounding areas.

In this paper, it is proposed the use of partial convolutional neural networks (PCNN) for multispectral satellite images inpainting obtained from the Sentinel-2 mission. The results of the efficiency study when reconstructing satellite images using PCNN and the traditional neural network U-Net are presented.

Partial convolutional neural network. A partial convolution layer is a layer that contains a masked and renormalized convolution operation followed by a mask update operation. The main difference between this layer and the layer of a convolutional neural network (CNN) is the presence of an automatic mask update operation, which removes a part of the mask where pixels have already been restored [2; 3]. The use of partial convolutions is such that in the presence of a binary mask, the convolution results depend only on unmasked pixels. To solve the problem of image inpainting, it is proposed to use PCNN with a U-Net encoder-decoder architecture. The original architecture is modified by replacing the convolutional layers of the original CNN U-Net with partial convolutional layers.

Inpainting results on the test area. In order to evaluate the performance of the proposed PCNN, an image of a test area with clouds (Fig. 1*a*) and an associated binary mask (Fig. 1*b*) were used as the network input. To generate the binary mask, we used a classification algorithm based on the KNN method. The classifier is able to identify clouds (black pixels) and the background (white pixels).

Visually analyzing the results, in Fig. 1*c* it is noted that the restored areas under clouds smoothly integrate into the surrounding context. It is noticed that the segmented restored image in Fig. 1*d* is completely cloudless, which means the clouds were removed successfully, and the network shows a high performance when inpainting satellite images.

Performance evaluation of the inpainting algorithm. In order to evaluate the accuracy of multispectral satellite image inpainting using PCNN, a test dataset was built. This dataset consists of 3630 satellite images and their segmented reference masks. In addition, 3630 random binary masks were generated for cloud simulation and inpainting purposes. A comparison between the segmented reference masks and the segmented

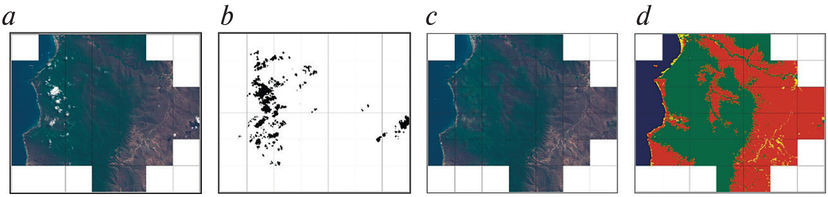

Fig. 1. Inpainting results on the test image: *a* – original RGB composite image, composed of the 4th (R), 3rd (G) and 2nd (B) channels; *b* – associated binary mask: *c* – RGB-composition of the reconstructed image using PCNN, composed of the 4th (R), 3rd (G) and 2nd (B) channels; *d* – semantic segmentation of the reconstructed image

reconstructed images was carried out. Based on the results of 3630 experiments, the following metrics were calculated and are shown in Table 1: the mean absolute error (MAE) and the average Jaccard index, also known as mIoU. In addition, the results of image inpainting using the U-Net network with traditional architecture were obtained. From the comparison between the MAE and mIoU metrics in Table 1 for each of the CNN models, it follows that the PCNN shows the best results in terms of accuracy.

Table 1

Evaluation metrics for image inpainting

Model	MAE	mIoU
CNN U-Net	0,0382	0,8512
PCNN	0,0288	0,9344

Conclusions. In this work, it is proposed to restore multispectral satellite images using PCNN after removing clouds. The results of the research showed that the PCNN achieves more accurate outcomes, when restoring multispectral satellite images than the U-Net network with traditional architecture. At the same time, the PCNN restores areas with a minimum error after removing clouds of any shape, size, location, and distance from the image boundaries.

REFERENCES

1. **Warren S.**, **Eastman R.**, **Hahn C. A.** Survey of Changes in Cloud Cover and Cloud Types over Land from Surface Observations, 1971-96. Journal of Climate. 2007. № 20 (4). P. 717–738. DOI:10.1175/JCLI4031.1

2. **Liu**, **G.**, **Reda**, **F. A.**, **Shih**, **K.J.**, **Wang**, **T.-C.**, **Tao**, **A.**, **Catanzaro**, **B.** Image Inpainting for Irregular Holes Using Partial Convolutions. arXiv: 1804.07723 [cs.CV]. 2018. DOI:10.48550/arXiv.1804.07723

3. **Gruber**, **M.** Partial Convolutions for Image Inpainting using Keras [Electronic recourse]. GitHub, Inc. March 1, 2019. URL: https://github.com/MathiasGruber/PConv-Keras (accessed on 03.03.2023).