CarcassonNet: A Deep Learning Approach for Mapping Hollow Roads in LiDAR Data

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Introduction and overview

For a number of years there has been a steady increase in the implementation of archaeological object detection techniques, with a trend towards Machine and Deep Learning methods (Lambers et al. 2019). The detection rates of these algorithms are now exceeding 80% for compact, localized objects, such as barrows and charcoal kilns (e.g. Verschoof-van der Vaart and Lambers 2019). However, little research has been done on the detection of more complex landscape objects, such as Celtic fields and hollow roads. While hard to discern in the present-day landscape, hollow roads appear in LiDAR data as clear longitudinal objects (Kirchner et al. 2020). As these roads are remains of trade and migration networks of the past, mapping them manually on a landscape-wide scale could be useful input to other archaeological research questions, but often proves difficult due to the sheer quantity of hollow roads.

The same problem is already addressed in modern-day road mapping (e.g. Abdollahi 2020) and often solved with Deep Learning methods, but these do not translate well to the problem at hand due to differences between hollow and modern roads:

(1) hollow roads lack the similarity of modern roads; (2) due to the long temporal and repeated use of specific routes, hollow roads tend to manifest in the shape of several linear tracks with slightly different orientation with multiple overlaps between the individual tracks; (3) due to geomorphological (e.g. erosion and drift) and anthropogenic interference (e.g. agricultural and building activities), hollow roads are often only partially preserved and regularly are dissected by modern (landscape) objects.

The CarcasonNet workflow

In this paper we present a novel approach to automatically detect and trace hollow roads in LiDAR data, using a combination of Convolutional Neural Networks (CNNs) and image processing algorithms. This approach, which we call CarcassonNet, has been specifically developed for the archaeological domain, focusing on being computationally light and particularly suited for reconstructing partially preserved and intersected (hollow) roads. In this research we have taken inspiration from the well-known board game Carcassonne (developed by Klaus Jürgen-Wrede and published by Z-Man Games; https://www.zmangames.com/en/products/carcassonne/), hence the name CarcassonNet (see Fig. 1). In this game a medieval landscape, including roads, is constructed by laying square shaped cards, so-called terrain tiles, end-to-end. While the roads depicted on the terrain tiles differ little individually, extensive road networks of varying shapes can be made. The same could be said for hollow roads: while these differ when looked at as whole objects, the difference between (small) sections of hollow roads is minimal.

Figure 1: Example of complex road patterns in the boardgame Carcassonne.

Therefore, using individual sections, as opposed to the whole hollow road as a single input image, has several advantages: (1) the use of tiles (and therefore multiple sections per single hollow road) makes it much more cost-effective to create a sufficient training dataset to successfully implement Deep Learning algorithms; and (2) by using this method, the CNN is only used for image classification, a relatively simple task, instead of more complicated tasks such as segmentation.

In our approach we use LiDAR data from a hollow road rich part of the *Veluwe* in the central part of the Netherlands. The interpolated Digital Terrain Model (DTM) is processed and divided into square tiles of 40 by 40 metres.

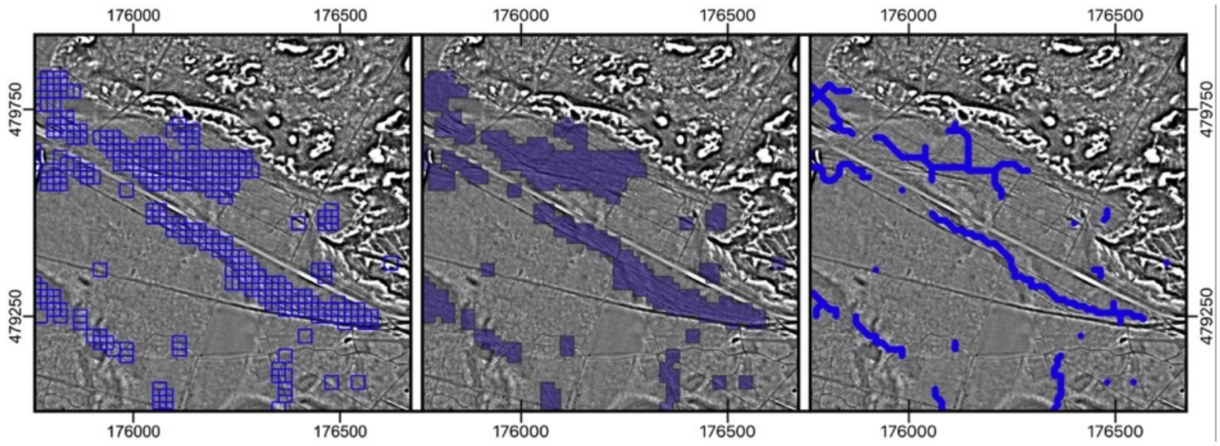

Figure 2: Excerpts of LiDAR data, visualized with the Local Relief Model, showing: the results of the classification (left); the derived polygons showing the location of the hollow roads (centre); and the derived lines depicting the route network (right).

The tiles are divided between "hollow road" or "empty" and used as a training dataset to transfer-learn a pre-trained ResNet34 (He et al. 2016) CNN model. Subsequently, the trained model is tested on tiles from another part of the research area (Fig. 2, left).

The output of the classification—groups of tiles classified as hollow road—are fed into a post-processing step: To obtain the location and direction of the roads, they are converted into polygons in QGIS 3.4 (Fig. 2, center). Subsequently, these polygons are turned into lines, by using the approach taken by van Etten (2019): A 'skeleton' is created from the polygons with the *scikit-image Skeletonize* package and subsequently rendered into a graph structure with the *sknw* package in Python 3.7. The result is a set of closely spaced points depicting the course of the detected roads. Subsequently these are turned into vectors with the *Buffer* and *Dissolve* processing tools in QGIS (Fig. 2, right).

Results and discussion

Experiments conducted with CarcassonNet have shown that this workflow is able to detect and trace hollow roads in LiDAR data. Road patches are recognized with an accuracy of 89% in the Veluwe test dataset. The results of this research can be used for the reconstruction of these vanished and abandoned routes and answer archaeological questions about human-landscape interactions.

Further research will focus on the improvement of the performance of CarcassonNet on small, individual hollow roads, for instance by implementing segmentation in the post-processing step. Also, further incorporation of CarcassonNet into QGIS is envisioned.

References

Abdollahi, A., Pradhan, B., Shukla, N., Chakraborty, S., Alamri, A.: Deep Learning Approaches Applied to Remote Sensing Datasets for Road Extraction: A State-Of-The-Art Review, Remote Sens. 12 (2020) 1444. https://doi.org/10.3390/rs12091444.

He, K., Zhang, X., Ren, S., Sun, J.: Deep Residual Learning for Image Recognition, in: 2016 IEEE Conf. Comput. Vis. Pattern Recognit., IEEE, Las Vegas, NV, 2016: pp. 770–778. https://doi.org/10.1109/CVPR.2016.90.

Kirchner, A., Herrmann, N., Stadtmann, R., Lahmer, T., Hille, L.M., Steinbrecher, T., Sauerwein, M.: Spatial analysis of hollow ways in the Hildesheimer Wald Mountains (Lower Saxony, Germany) as a model for mountainous regions of Central Europe. Erdkunde 74(1), 1/14 (2020). https://doi.org/10.3112/erdkunde.2020.01.01

Lambers, K., Verschoof-van der Vaart, W.B., Bourgeois, Q.P.J.: Integrating remote sensing, machine learning, and citizen science in Dutch archaeological prospection, Remote Sens. 11 (2019) 794. https://doi.org/10.3390/rs11070794.

Van Etten, A.: City-scale Road Extraction from Satellite Imagery (2019), http://arxiv.org/abs/1904.09901

Verschoof-van der Vaart, W.B. Lambers, K.: Learning to look at LiDAR: The use of R-CNN in the automated detection of archaeological objects in LiDAR data from the Netherlands, J. Comput. Appl. Archaeol. 2 (2019) 31–40. https://doi.org/10.5334/jcaa.32