

# Estimating Pixelwise Canopy Cover from RGB Orthoimagery using a U-Net Derivative



## Motivation

The structure of forest canopies is of great interest to biological and ecological researchers as it is one of the primary determinants of the microhabitat of a forest. One of the simplest forest canopy structure indicators is canopy cover (CC), a fraction ranging from zero to one defined as the proportion of ground covered by the vertical projections of tree crowns. Canopy cover is better suited for assessing carbon sequestration and biomass than other commonly used indicators like the normalized difference vegetation index (NDVI) since it is able to tell apart trees from ground vegetation. [1]

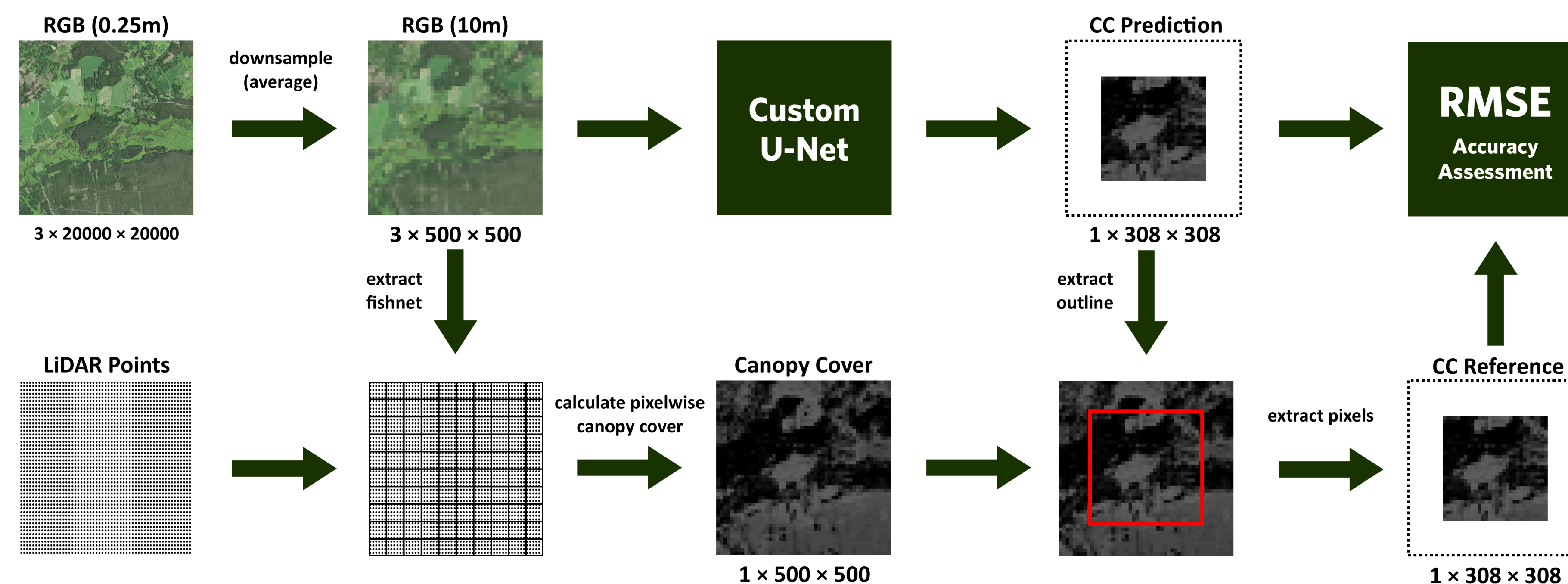
Researchers often deploy extremely time-consuming and labor-intensive methods like field surveys and manual interpretation of aerial photographs to assess canopy cover [2]. Hence the use of light detection and ranging (LiDAR) data from various airborne sensors has become a popular method for CC determination. LiDAR data points can be relatively reliably classified as canopy and ground and the ratio of first or single return points classified as canopy for any given area serves as a close approximation of canopy cover [3]. But the acquisition of LiDAR data is expensive and requires highly specialized equipment and expertise. Three-band RGB (red, green, blue) orthoimagery is much easier to acquire and is regularly captured by Earth-observing remote sensing satellites, making it globally available at high spatiotemporal resolution. Being able to reliably derive pixelwise canopy cover estimates from RGB orthoimagery would advance research by increasing the availability of CC data.

## Input and Reference Data

The Estonian Land Board performs LiDAR scanning in tandem with aerial photographing of a quarter of the Estonian landmass every spring and summer. Acquired orthoimagery tiles are publicly published along with their corresponding LiDAR point clouds. Summertime RGB orthoimagery were used as input data and canopy cover estimates derived from the corresponding LiDAR points serve as CC reference.

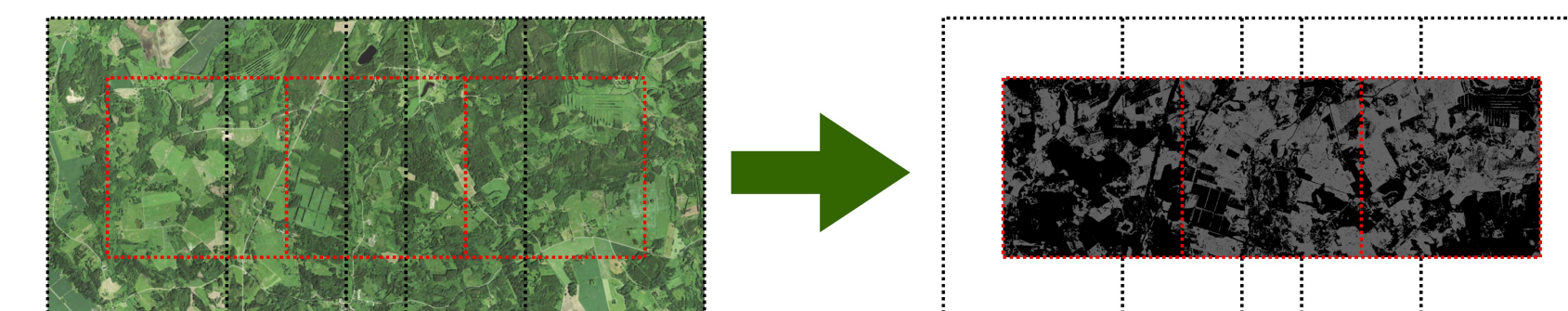
The original 0.25-meter resolution RGB orthoimage tiles were downsampled via averaging to a 10-meter resolution, resulting in three-band images with a size of 500×500 pixels. This was important to increase the number of LiDAR points per pixel. CC reference tiles were created by calculating the proportion of first or single return points classified as canopy for each pixel. Point densities for each pixel were calculated and 95% of the pixels had a point density of at least 0.1 points per square meter, which is considered the minimum point density required for reliable CC estimates [4].

## Analysis Procedure

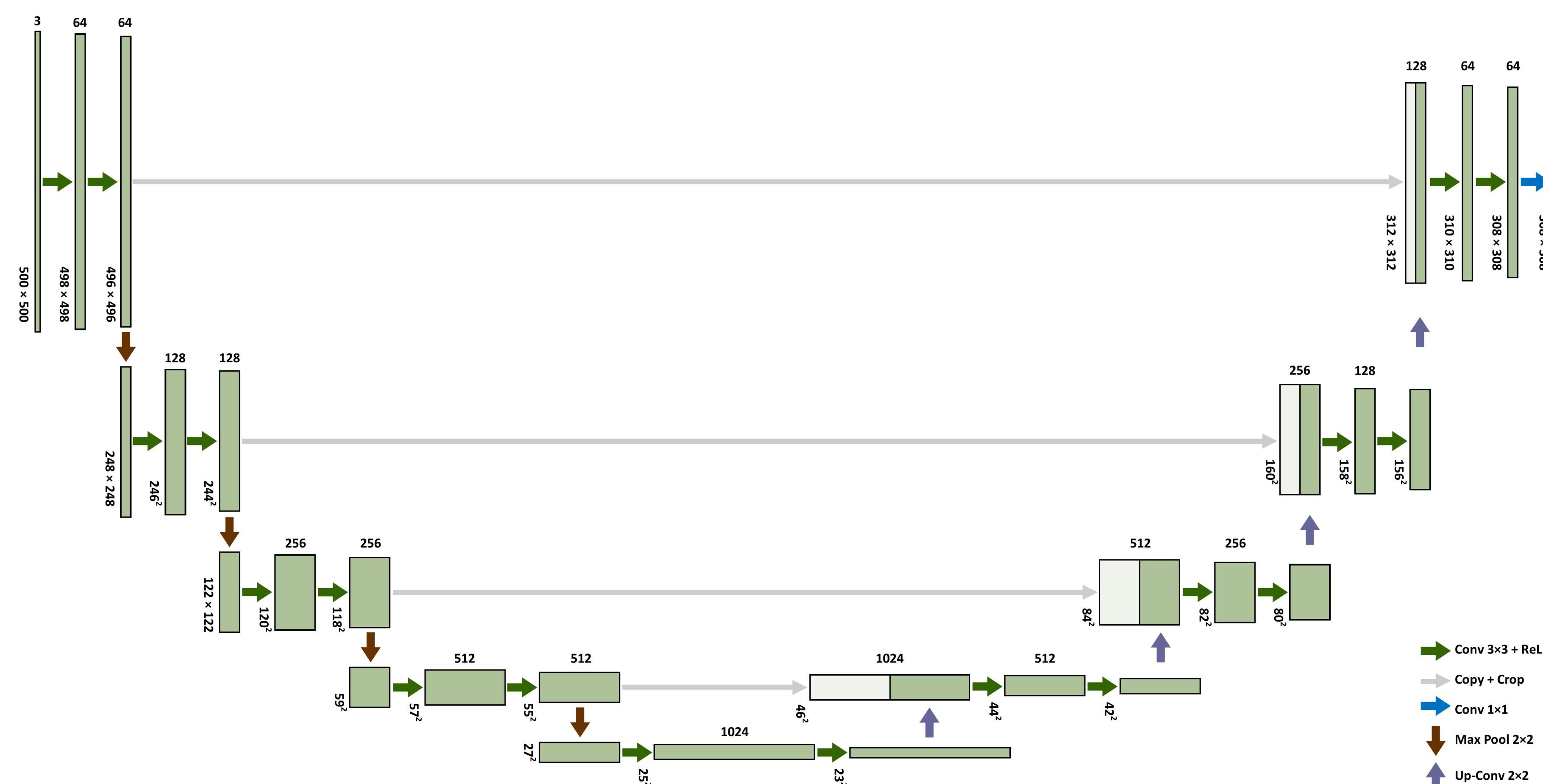


U-shaped convolutional neural networks (U-Nets) were originally developed for single-band biomedical image segmentation and have found much success in land cover classification tasks [5]. The canopy cover estimation problem is closely related to land cover classification, suggesting U-Net derivatives would perform well. An U-Net derivative was constructed by changing the original input size from 1×572×572 to 3×500×500 and replacing the SoftMax classification from the final step with a simple linear convolution.

The resulting output had a size of 1×308×308. While this means predictions were derived for less than 50% of the input pixels, it avoids interpolation, resulting in better accuracy and allows the creation of seamless estimations from arbitrarily large RGB orthoimages by using multiple overlapping tiles as model input.



## Network Architecture



## Parameters and Results

A total of 665 three-band RGB orthoimage tiles were used with 465 for training, 130 for validation, and 70 for testing, resulting an approximate 70-20-10 split. Stochastic gradient descent (SGD) optimization was used with 0.99 momentum and an initial learning rate of 0.012. A scheduler was used to decrease the learning rate by a factor of 0.5 if learning stagnated for more than one epoch. Accuracy was assessed using root-mean-square-error (RMSE) loss. Model training ran for 25 epochs with a batch size of five and resulted in test accuracy of approximately 93%. No indications of model overfitting were observed.

## Next Steps

Although the 93% accuracy of the custom U-Net is far superior to the average 80% accuracy of canopy cover estimation using traditional machine learning techniques, there is much room for improvement [4]. Model parameters should be optimized in an attempt to increase performance and additional input data from various seasons and climates and with differing spatial resolutions acquired to better generalize the model. As canopy cover is spatially autocorrelated, errors should be analyzed for spatial autocorrelation and convolutional layers reconfigured if necessary. NGR (near-infrared/NIR, green, red) and four-band RGB+NIR imagery should be experimented with to determine whether the addition of near-infrared reflectance increases model performance. Higher density LiDAR data should be obtained to increase the accuracy of reference CC data used for training.

Residual neural networks like ResNet have also been proven to be highly effective at pixelwise land cover classification indicating promising potential results when adapted for pixelwise canopy cover estimation. Models combining the architecture of U-Net with that of ResNet could also achieve high accuracies on pixelwise canopy cover estimation tasks and should hence be explored as well. Upon determination of the best model, a global canopy cover dataset should be constructed from widely available satellite imagery.

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