Dissertation Background

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Topic: Deep Learning for Earth: Monitoring active forest restoration projects with convolutional neural networks and high-resolution satellite imagery.

1. Background

Tropical forests are crucial for mitigating climate change and many environmental non-profit organisations, such as Conservation International continue to invest in active forest restoration projects. These projects consist of managing the planting of seeds to encourage tree re-growth: an approach which has been found to successfully reduce carbon dioxide emissions and to generate higher rates of carbon accumulation than naturally regenerating forests (Philipson et al., 2020). Despite these benefits, active restoration projects are costly and challenging to manage. Monitoring methods such as on-foot land surveys and LiDAR flyovers are expensive and unreasonable to conduct on large restoration sites. However, remote sensing data such as satellite imagery is freely available and combined with methods in machine learning offer an exciting alternative to future forest monitoring.

In recent years medium-resolution satellite imagery (10-30m) has been used for mapping large canopy covered forests. The results of (Hansen et al., 2013), (Ottosen et al., 2020) and (Brandt & Stolle, 2020a) provide some preliminary evidence that medium-resolution satellite imagery in combination with machine learning techniques can be used for land classification and for monitoring forest re-growth. In particular, (Brandt & Stolle, 2020a) showed that Sentinel-1 and Sentinel-2 imagery in combination with a convolutional neural network model can increase the accuracy of monitoring tree presence in areas with scattered tree cover by as much as 20%.

However, their experiments show that monitoring adolescent and sparse trees is difficult with medium-resolution satellite imagery since many individual trees often are smaller than the satellites resolution. This is particularly problematic for monitoring active forest restoration projects, since many of the trees are sparsely distributed and are often too small to be accurately detected by medium-resolution satellite imagery. Therefore, in my undergraduate dissertation, I plan to utilise recently licensed high-resolution satellite imagery (3-5m) and experiment with varying convolutional neural network model variants to identify and monitor sparse trees which are commonly found in active forest restoration sites.

2. Fiji Nakauvadra Active Forest Restoration

For the dissertation I have partnered with the non-profit environmental organisation Conversational International (CI) who have provided ground-truth data on an active forest restoration site in Fiji. CI are one of the world's largest nonprofit environmental organisations operating in over 30 countries with the mission of combating climate change and restoring natural ecosystems. The Nakauvadra Mountain Range site, is an active forest restoration project managed by CI in northern Fiji covering over 1,135 hectares. The project, which started in 2009, was implemented in order to plant native and non-native trees to increase the buffer zone between the Nakauvadra forest and the surrounding agricultural lands.

The site is one of the largest, oldest and most successful restoration projects managed by CI. The site covers an area of high biological diversity which was originally surrounded by grasslands that were slowly encroaching into the mountains following uncontrolled burning and unsustainable land clearing. The project is now more than 10 years into development and is being used as a model for restoration in Fiji as tree re-growth is now spreading into a neighbouring mountain basin (ConservationInternational, 2020).

Figure 1. Pictures from the Nakauvadra Mountain Range site showing changes from grasslands in 2009 to adolescent tree growth in 2017.

As ground-truth data, Conservation International have been supplied shape files containing the locations of 20 planting sites across the 1,135 hectare project from 2009 and 2015. Satellite imagery will then be used to then monitor the progress of these 20 planting sites with the aim of identifying tree re-growth and mapping sparsely distributed forest accumulation within the 10 year period.

3. Planet Satellite Data

High-resolution (3-5m), open-source satellite data from Planet (PlanetLabs, 2018) will be used for training various convolutional neural networks to identify sparse trees in the Nakauvadra forest restoration site. Planet Labs Inc. operates the largest fleet of Earth imaging satellites, with around 180 "Dove" satellites currently in orbit and imaging the entire Earth, every day. Dove imagery has been previously used to map coral reefs and to monitor tropical forest carbon stocks (Csillik et al., 2019);(Asner et al., 2017) and to my knowledge, Planet Dove images have not yet been used to monitor active forest restoration sites.

In October 2020, the Norway International Climate Forests Initiative licensed Planet satellite imagery in the tropics region and have made all data freely available for the use of forest monitoring and combating climate change (NICFI, 2020). Specifically, I will use bi-annual and monthly high-resolution data to generate training, validation and test data to build the model. The aim of the project is to understand the capacity of open-source high-resolution satellite data to map distributions of trees and forests in the Fiji restoration site, and to understand the generalization performance of convolutional neural networks in mapping trees in spatially disconnected regions.

All high-resolution imagery will be accessed via Planet's Data API which is a RESTful API interface to Planet's complete imagery catalogue. Initially I have been using the free licence supplied by the Norway International Climate Forest Initiative that gives me access to base maps for the tropics (Fiji included), however I have recently applied for the Educational Licence which allows students and researchers to access historical archives for planetary data.

4. Model: Convolutional Neural Networks

Over the past decade, there have been various attempts to quantitatively map tree cover using a variety of supervised and unsupervised machine learning methods with medium-resolution imagery. One of the most popular approaches developed by (Hansen et al., 2013) mapped tree cover based on Landsat (30m resolution) imagery and a per-pixel random forest classifier. However, because (Hansen et al., 2013) was designed for monitoring large, contiguous, closed-canopy forests, it routinely underestimates sparse tree cover and is not accurate in heterogeneous landscapes such as urban environments or regions with fragmented forests such as those found in active restoration sites. Furthermore, regional models have identified that (Hansen et al., 2013) underestimates tree cover by up to 80% in heterogeneous landscapes and therefore illustrating the limitations of per-pixel machine learning classifiers with medium-resolution satellite imagery such as Sentinel 1, Sentinel 2 and Landsat (Brandt & Stolle, 2020b); (Ottosen et al., 2020); (Milodowski et al., 2017).

During the same period, in the computer science domain, deep convolutional neural networks (CNNs) have become the state-of-the art method for various computer vision tasks including object recognition (Krizhevsky et al., 2012) and image segmentation (Sultana et al., 2020). CNNs are a subclass of deep neural networks, most commonly applied to analysing visual imagery, that learn spatial patterns by subsequently applying convolutional operations between the input data and learned weights of the model (Goodfellow et al., 2016).

In recent years, CNN models have been introduced to the geoscience domain and have established new best-in-class accuracies for a number of remote sensing tasks, such as land use classification (Ulmas & Liiv, 2020) (Rakhlin et al., 2018) and building identification (Zhang et al., 2018). In particular, many studies have found that specifically the U-net CNN architecture outperforms other machine learning classifiers for remote sensing tasks with high-resolution imagery (Wagner et al., 2019) (Diakogiannis et al., 2020) (Li et al., 2018) (Feng et al., 2019). The U-Net architecture, first proposed by (Ronneberger et al., 2015) in the field of medical imaging, is a variant of a deep convolutional neural networks consisting of a contracting path and an expansive path, which gives it the U-shaped architecture.

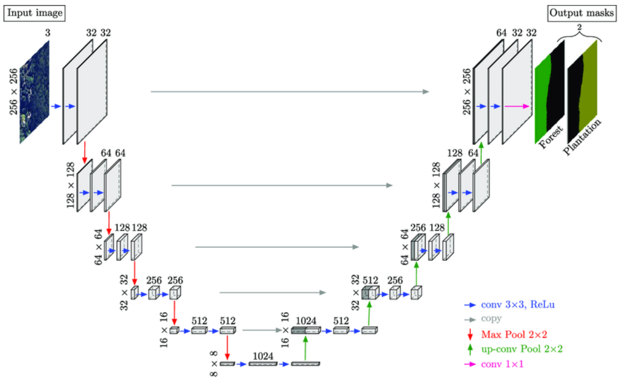

Figure 2. U-net architecture for the forest types segmentation, adapted from Ronneberger et al. (2015). The number of channels is indicated above the cuboids and the vertical numbers indicate the row and column size in pixels (Wagner et al., 2019).

The recent success of deep learning methods in various remote sensing tasks gives promise to the application of convolutional neural networks in active forest restoration monitoring. For my undergraduate dissertation I aim to explore the performance of various CNN models in mapping distributions of trees and forests in the Nakauvadra restoration site. I will use the PyTorch open source machine learning library to implement model variants and compare their generalization performance across varying spatially disconnected regions in Fiji.

5. Next Steps

Data gathering: Using the shape files supplied by Conservation International, download high-resolution imagery (4.77m) for the 20 seed plantation sites in the Nakauvadra mountain range using Planet API. Take time to manually label binary classifications of trees vs no trees using acquired high-resolution satellite imagery and open source GIS software. Split data into training, validation and test set. Deadline: November 2020

Model Training: Begin to develop baseline CNN model and experiment with various deep learning variants, including U-Net. Take special consideration of cross validation techniques with spatial and temporal data, ensuring to implement the block cross-validation as per (Roberts et al., 2017). Aim is to develop a baseline image segmentation model that can successfully identify and map distributions of trees and forest in the Fiji restoration site. Deadline: December 2020

Model Tuning and Inclusion of Change Detection Monitoring: After developing a baseline CNN model for image segmentation and mapping distributions of sparse trees in the Nakauvadra restoration site, appropriate hyperparameter tuning will be undertaken to maximise generalization performance of the model. Furthermore, during this time, I aim to explore methods for including historical time-series satellite imagery to track forest re-growth and change detection over time. This is particularly crucial for active forest restoration monitoring and would be a major milestone to reach as part of the undergraduate dissertation project Deadline: January-February 2020.

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