CS486C – Senior Capstone Design in Computer Science

Project Description

Project Title: Facilitating Forest Monitoring with Mobile Lidar	
Sponsor Information: NORTHERN ARIZONA UNIVERSITY Ecological Restoration Institute	Andrew J. Sánchez Meador, Ph.D. Executive Director, Ecological Restoration Institute Northern Arizona University andrew.sanchezmeador@nau.edu

Project Overview:

For the last century, forest management centered around timber production and fire exclusion has lead to significant degradation of forested ecosystems. As tree densities have increased and fuel loads (combustible woody material) built up, overall forest health has been reduced and the risk of catastrophic wildfires have increased significantly. A central mission of NAU's Ecological Restoration Institute (ERI) has been assisting with the recovery of these systems, restoring forest health by promoting modern science-driven management practices, and developing and deploying practical methods to restore western forestlands. Such actions often necessitate both collaboration and adaptive management to address uncertainties and the mistrust that results from incomplete or incorrect information needs. ERI works with affected entities to restore western forest landscapes using innovative technologies, provide novel solutions for the use of tree biomass and wood products and actively engage partners and communities that influence land management and depend on these forests.

Advancing climate change and the resulting increased stress it imposes on forest ecosystems has created a new sense of urgency, forcing scientists and forest managers to increase the scale and pace of restoration to match the increasing scale of important disturbances, such as fire and prolonged drought. This has resulted in forest restoration activities that are taking place over increasingly larger spatial scales and with little-to-no time to plan and/or consider the long-term impacts.

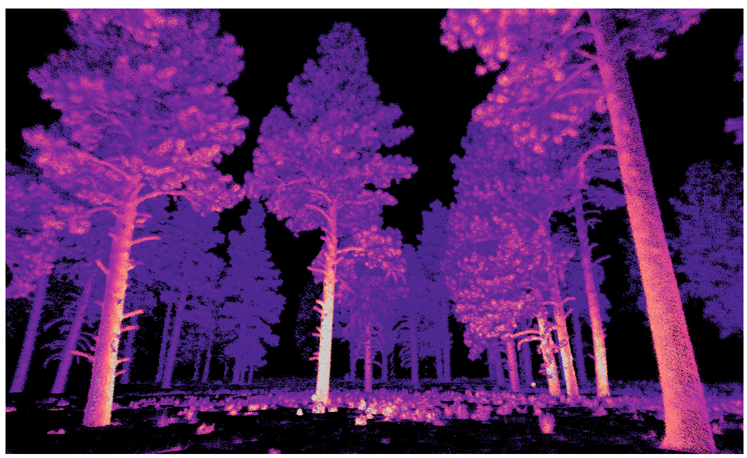

Figure 1: Example MLS point cloud from a ponderosa pine forest near Flagstaff AZ colored by point density containing over 40 million points. .

The Problem: rapid assessment of evolving forest conditions

Instrumental to this work is an accurate understanding of forest conditions, and the ability to monitor these forests over large temporal and spatial scales. Traditional intensive monitoring methods are not designed for use by citizens, are limited in their geographic scope by the costs of field data collection and processing, and provide no visual information to help the public understand the consequences of the actions. At the same time, the recent development of scanning technologies like Simultaneous Location And Mapping, and SLAM-based mobile lidar scanning (MLS) that produce high-resolution 3d data sets in the form of point clouds could provide an accurate assessment of ecosystem structure quickly and at substantially lower costs. However, translating the point cloud data into a usable form (e.g. 3d visualizations) is a challenge for non-technical ecologists and managers. What is needed is a powerful informatics tool that provides an easy-to-use graphical interface to MLS datasets that allows users to quickly locate and view relevant point-cloud MLS data, and supports rapid application of these data to help guide forest management planning.

Solution Vision: A secure, web-based tool and graphical interface to MLS data.
This project will combine a team of ecologists, managers and CS students to create a Shiny-based web-application and supporting R and C++ backend, that will allow high-density MLS-derived point cloud data to be processed to rapidly monitor and evaluate the effects of forest treatments and disturbances, building on the foundational functionality already present in the lidR package (Roussel et al. 2021). While the lidR package has a wealth of functionality that can handle large datasets efficiently, it was not developed for the application of MLS data and thus lacks several key features; also, being merely an R package, it lacks a GUI for easy use by ecologists and managers.

Solving this problem will require addressing two related but distinct challenges: a data processing and analysis core module that handles core processing of MLS data and production of visualizations; and an interface module that provides GUIs for efficiently communicating monitoring information to ecologist and managers. Modularizing the design in this way is important: we want a tool that provides base functionality for processing MLS point cloud data, but which can be expanded upon by an open-source user base to develop any number of GUIs or tools to allow ecologists and managers to explore and communicate the effects of forest treatments and disturbances in various ways.

The team will be well supported by domain experts: the ecology and management team will provide MLS point cloud data for a wide range of scenarios (conifer/hardwood, untreated/treated, homogeneous/heterogenous structures, etc.), consult on the workflow needed to process these data, and provided information on the desired summary information that would be necessary to evaluating change.

A bit more specifically, we envision a Shiny app wrapping an R package that uses and expands upon the lidR (Roussel and Auty, 2021) package's functionality (possibly as a plugin) to read MLS data which constitutes multiple scans of the same area, processes it to provide ecologically pertinent attributes, such as height, volume, above-ground biomass and individual tree location, and uses the multiple temporal nature of the data to report monitoring information (i.e., what's changed?). A major challenge will be developing a solution that is scalable with larger point cloud datasets and a web app front end that provides a clear visualization and easy-to-use GUIs. Some specific features of this software product could include:

Basic, minimal viable product:

- A set of memory and efficient processing functions that, once MLS data are read in, allow for tree boles to be isolated from foliage and the ground using eigen decomposition and geometry computations (e.g., Liang et al., 2014)
- Utilizes Random Sample Consensus, or RANSAC, cylinder fitting to estimate tree size at 1.37m above the ground, location and provides some estimate of tree height (i.e., the highest point in the identified bole).
- Has the ability to calculate differences between observed ecologically pertinent attributes, such as height, volume, above-ground biomass and individual tree location at two points in time.
- Is able to visualize the point cloud, the resulting tree attribute information, and allow the user to interact (zoom in/out, rotate, toggle on/off) with the data and summaries.

Complete, a well-appointed app. All elements of basic core, plus

- Utilizes parallel processing and data chunking to allow for processing to run on a variety of computer profiles and scalability.
- RANSAC could efficiently handle estimating log (a downed tree that is not vertical and contacts the ground in multiple locations) sizes too.
- Synchronized visualization of the point clouds at the two points in time.

Nice bells and whistles: stretch goals:

- Vignettes explain the functionality of the package and the Shiny app.
- Package uploaded and passing all CRAN checks so it can be an official "CRAN" package.

We look forward to working with CS team closely both in the planning phase and the later development phase to refine these elements. Depending on the design, ecologists and managers could use the app to quickly assess the effects of a treatment or disturbance, adapt their course of action based on the information provided, and communicate these results using the app's visualizations. Ideally, the package would be cross-platform and could be released as an official package on GitHub and CRAN as part of the R Project.

Knowledge, skills, and expertise required for this project:

- C++ programming skills
- Familiarity or interest in statistical and scientific computing, specifically the R environment.
- Interest in CS applications for forest and/or woodland ecosystems.

Equipment Requirements:

- The ecology team will provide an opportunity for the students to collect MLS data if desired, but otherwise example dataset will be provided.
- There should be no equipment or software required other than a development platform and software/tools freely available online.
- If Monsoon is used, access to Monsoon will be provided by the client in the later development phases to test scalability, when a prototype becomes available. Access to a workstation running Windows Server or Linux can be provided.

Software and other Deliverables:

- The application/R package as outlined above, tested and refined with project partners/end-users.
- Standard R documentation (see: https://r-pkgs.org/man.html) and two vignettes as outlined above.
- Complete professionally-documented codebase, delivered as a repository in GitHub (e.g., (e.g., see a great example here: https://github.com/Jean-Romain/lidR).

References

Roussel, J.R., Auty, D., Coops, N. C., Tompalski, P., Goodbody, T. R. H., Sánchez Meador, A., Bourdon, J.F., De Boissieu, F., Achim, A. (2020). lidR : An R package for analysis of Airborne Laser Scanning (ALS) data. Remote Sensing of Environment, 251 (August), 112061.

Jean-Romain Roussel and David Auty (2021). Airborne LiDAR Data Manipulation and Visualization for Forestry Applications. R package version 3.1.0. https://cran.r-project.org/package=lidR

X. Liang, V. Kankare, X. Yu, J. Hyyppä, M. Holopainen. (2014) Automated stem curve measurement using terrestrial laser scanning. IEEE Trans. Geosci. Remote Sens., 52 (3) 1739-1748