Awards issued prior to January 20, 2025, were funded under previous Administrations and may not reflect the priorities and policies of the current Administration.

United States Department of Agriculture
Project Initiation

Project Data for Accession Number 1032672

Project Title

Improving Forest Management Through Automated Measurement of Tree Geometry

Project Details

Sponsoring Institution National Institute of Food and Agriculture	**Project Status** ACTIVE
Funding Source NIFA Non Formula	**Grant Year** 2024
Grant No. 2024-67021-42879	**Cumulative Award Amt.** $598,947.00
Proposal No. 2023-11367	**Multistate No.** (N/A)
Project Start Date Aug 01, 2024	**Project End Date** Jul 31, 2028
Program Code [A1521] Agricultural Engineering	

Project Director

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Recipient Organization

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Performing Department

(N/A)

Non Technical Summary

Forests have long provided human societies with food, fuel, fiber, and other services. As human populations grow and climate change intensifies, demand for forest goods and services are rising. However, contemporary forest management continues to rely on sparse information collected using centuries old methods, and there is a critical and urgent need from forest stakeholders for technologies to support data-driven decision making. We propose a transdisciplinary-engineering solution, both in hardware and software, to meet stakeholders' needs for sustainable and profitable forest management through digital twinning of forests.We will develop an end-to-end digital-twinning system for fast and accurate forest inventory, by combining cutting-edge remote sensing techniques and AI-based analytics. We will capture forest biometric and structural data using high-precision LiDAR coupled to GNSS and IMU to improve accuracy (Objective 1). Constituent parts of trees and forests will be reconstructed from LiDAR point clouds and assembled into digital twins (Objective 2). Digital twins will be analyzed and quantified to extract information relevant

to stakeholder objectives such as timber production and carbon storage, and these measurements will be validated in a wide range of forest conditions to ensure accuracy and robustness (Objective 3). We will engage stakeholders in all stages of the development process to ensure the final result is useful, useable, and meets the needs of the end user. This work has the potential to revolutionize forest management by supplying forest managers with detailed, precise information at speeds and prices that are a fraction of existing methods.

Animal Health Component

Animal Health Component: 0%

Research Effort Categories

Basic	20%
Applied	20%
Developmental	60%

Classification

Knowledge Area (KA)	Subject of Investigation (SOI)	Field of Science (FOS)	Percent
123	7210	2020	100%

Knowledge Area

[123] Management and Sustainability of Forest Resources

Subject Of Investigation

[7210] Remote sensing equipment and technology

Field Of Science

[2020] Engineering

Keywords

Forestry, LiDAR, Deep Learning, 3D Reconstruction, Digital Twinning, Instrument Integration

Goals / Objectives

Our long-term goal is to put advanced technologies into the hands of forest stakeholders (landowners, managers, researchers, etc.) to facilitate data-driven, sustainable, and profitable forest management. Our project will develop, validate, and demonstrate novel, scalable methods to rapidly capture, reconstruct, and extract information on forest structural features that directly measure the quantity and quality of forest products (timber, biomass, etc.). This work has the potential to revolutionize forest management by supplying forest managers with detailed, precise information at speeds and prices that are a fraction of existing methods. We will accomplish this goal through three objectives: Objective 1: [Data Capture] Develop data capture instrument systems that leverage cutting-edge sensing technologies to produce a comprehensive forest inventory data stream using terrestrial/UAV LiDAR. Building on our previous work in less challenging environments, we will develop novel methods to integrate LiDAR, Global Navigation Satellite Systems (GNSS), and Inertial Navigation Systems (INS) data to solve the critical issue of frequent GNSS signal

outages when working under forest canopies. Our data capture systems will be capable of recording complementary geospatial data for deriving essential forest inventory metrics such as detection (counting), location mapping, and high-resolution point clouds necessary for forest-scale and stand-level reconstruction.Objective 2: [Reconstruction] Develop AI-based data processing tools to reconstruct the forest at the individual tree level from LiDAR point clouds. At the core of this approach is a novel AI-based analytical system that relies on biologically informed developmental models of tree growth patterns to bootstrap the 3D structure of the forest from LiDAR point clouds. This method employs deep neural models to extract components of trees from point clouds. The components are assembled following developmental rules to provide accurate 3D geometry of tree structure. Our analytical pipeline is essential to automate the analysis of the big data generated by LiDAR.Objective 3: [Information Extraction and Validation] Develop software for automated extraction of biometric information. Using the high-precision digital twins from Objectives 1 & 2, we will develop software to automate extraction of information essential for effective forest management decisions, including traditional biometrics (e.g., diameter, volume, crown size, etc.) and forest structure, facilitating precision forest management. The accuracy and robustness will be rigorously tested in a range of conditions (natural forest vs. plantation, young vs. old) to understand the limits of generalizability and accuracy. Automation and accuracy are keys to the widespread adoption by industry and government stakeholders who are not specialists in these methods.

Project Methods

Objective 1 [Data Capture]:Summary:Techniques to be employed in this project, including their feasibility and rationale: We will develop data acquisition platforms and system-driven strategies for automated detection and matching of tree and terrain features in UAV and Backpack LiDAR point clouds for system calibration and trajectory enhancement. Proposed project activities:Extracted and matched features in multi-platform/temporal point clouds will be used in an optimization strategy to reduce discrepancies among these features.Expected results:A set of systems/algorithms that will result in high resolution, well-aligned point clouds from multi-temporal Backpack and UAV LiDAR data, which is coupled with precisely geo-tagged RGB imagery.Data analysis and interpretation:We will develop, test, and validate the performance of developed systems/strategies in a range of forest types. We will also develop quality control metrics for evaluation of the alignment of multi-platform LiDAR point clouds as well as the respective geo-tagged imagery.Pitfalls and limitations:The success in deriving well-aligned point clouds is contingent on successful identification of corresponding features in UAV and Backpack LiDAR data. Erroneous matches will affect the quality of the final point clouds. To mitigate such sensitivity, an outlier detection procedure will be implemented, and extracted features from both geometric/morphological and deep learning strategies will be used to increase the robustness against possible outliers.Objective 2 [Reconstruction]:Summary:Techniques to be employed in this project, including their feasibility and rationale:We will use a deep neural model to find the belonging of a point to either branch or junction. The points will then be interpolated into tree parts and the tree parts will be used to build the entire 3D forest model by growth simulation and interpolation.Proposed project activities:We will develop, test, and validate a set of algorithms that will input point clouds and produce 3D geometries.Expected results:A set of algorithms to 3D reconstruct point clouds into tree models. Several fully reconstructed 3D point clouds of forests. Training data sets of several tree species.Data analysis and interpretation:We will validate the precision by manually measuring trees and the algorithms for their speed and precision. The data will be interpreted in Obj. 3.Pitfalls and limitations:The main limitation comes from the Nyquist sampling limit of the point clouds. Small branches will be immersed in noise, and their reconstruction will be increasingly difficult. We want to provide an insight into this limit, and we will carefully measure and express the smallest possible part that can be reconstructed depending on the data precision.Objective 3 [Information extraction and validation]:Summary:Techniques to be employed in this project, including feasibility and rationale:We will extract biometric and structural information relevant to forest management objectives from digital twins. We will validate this information by comparing to manual measurements and by completing this process in a wide variety of forest types.Proposed project activities:Extracted information will be checked for accuracy and precision and the robustness of our approach will be evaluated.Expected results:A suite of digitally derived biometric and structural measurements to provide better information to forest stakeholders, improving forest management.Data analysis and interpretation:Extracted measurements will be compared to rates of measurement error associated with equivalent manual methods. We will evaluate the influence of forest type and condition on sources and magnitude of

error.Pitfalls and limitations:The accuracy of some biometric and/or structural features may be inherently more difficult to constrain due to a wide range of possible issues. Cross-validation with manual methods and across a diverse set of forest conditions will allow identification of error sources. Our iterative workflow will allow for continuous refinement.