

Science

FINDINGS

INSIDE

Developing Protocols.....	2
Profile of a Mangrove.....	4
From Trees to Forests.....	4
Snapshots in Time.....	5

issue two hundred nine / september 2018

"Science affects the way we think together."

Lewis Thomas

A Fuller Picture: The Building Blocks of a 3-Dimensional Natural Resource Inventory



In the 1850s, photogrammetry used a kite-mounted camera to take aerial photos to develop 3-dimensional topographic maps. Today, researchers can use drones, such as the customized one pictured here. A digital 3-dimensional likeness of a tree, or other object, can be reconstructed from overlapping 2-dimensional images and used to calculate volume or other metrics that are difficult to gather precisely when using manual methods.

"A mind that is stretched by a new idea can never go back to its original dimension."

—Oliver Wendell Holmes

Each summer, field crews survey forests across the country, often bushwhacking through dense undergrowth and clambering up steep slopes while following global positioning

IN SUMMARY

Accurate measurements of natural resources are a prerequisite for resource assessment. Demetrios Gatziolis, a scientist with the USDA Forest Service Pacific Northwest Research Station, and his colleagues with Washington State University developed and tested protocols for using structure-from-motion photogrammetry to obtain data that can be used to construct 3-dimensional (3-D) representations of trees, other vegetation, and down wood. This type of photogrammetry is a remote-sensing technique based on a sequence of digital images or video footage. Gatziolis and his colleagues focused on developing protocols for using it under the forest canopy. Their method can serve as a guide for others interested in obtaining inexpensive, precise 3-D data of trees in field plots. The researchers continue to perfect the technology so it can be reliably deployed by field crews with a minimal amount of training.

The researchers have also applied the technique in a variety of environments, including surveying aboveground roots of mangroves, which play a key role in mitigating shoreline erosion. Working in Mount St. Helen's posteruption landscape, the researchers are supporting ongoing work to monitor revegetation, capturing metrics that would be impossible or extremely labor intensive to collect by hand. Photogrammetry yields digital records of conditions at a specific time. This may create possibilities to backtrack in the future and analyze parameters that aren't currently being monitored.

system coordinates to find study plots. Once they find the plots, these technicians with USDA Forest Service's Forest Inventory and Analysis (FIA) program set transects, measure the trees, note their health, and depending on the plot and the year, gather information on the size and amount of down wood, understory vegetation, and more. This information about individual trees, and cumulatively, the health of the stand, is key to forest management. Critically, forest managers want to know how these metrics change over time in response to management or disturbance. The FIA program has been surveying the nation's forests and providing many of these metrics since 1928.

Technological advances continue to provide new ways of collecting information during these field surveys; electronic data loggers, for example, have generally replaced "write-on-rain" paper notebooks. The challenge is always balancing cost, reliability, and accuracy of data collection. Over the past few years, Demetrios Gatzliolis, a member of the FIA program at the Forest Service's Pacific Northwest Research Station, has become increasingly optimistic about using structure-from-motion photogrammetry as a component of field surveys to provide accurate, consistent information about forests.

Photogrammetry is a technique for extracting geometric measurements from 2-dimensional images with overlapping content. A particular branch, for example, serves as a key point—visible in multiple images but

 KEY FINDINGS 
• The precision of photogrammetry measurements matches or exceeds the precision of traditional inventory methods for the majority of parameters tested. Photogrammetry can quantify additional parameters such as canopy cover and closure, intensity and duration of solar illumination, and tree competition, that are not readily assessed through established procedures.
• Photogrammetry technology is traditionally deployed using airborne platforms, which now includes drones. It can be used under forest canopy for near-ground measurements, such as volume of coarse woody debris, which is infeasible by standard remote-sensing approaches.
• Photogrammetry delivers detailed 3-dimensional scene representations conducive to extracting precise dimensionality measurements of objects. Stored digital representations can be used in the future to assess the present value of parameters currently not considered, for example the foliage volume of understory vegetation.

from different angles. Algorithms are used to triangulate these key points with the position of the camera. The resulting point cloud data are then reconstructed using a graphic interface computer program and presented as a 3-dimensional image recognizable to the human brain. It's a technique that makes precise, 3-dimensional measurements of a tree (or other objects) possible. This information can then be used in modeling tree growth and assessing change over time.

The origins of photogrammetry are traced to Leonardo da Vinci who articulated the concepts of perspective and projective geometry—envision pyramidal lines extending from an object when viewed from different perspectives. In the 1850s, Aimé Laussedat applied the concepts when he experimented with developing topographic maps based on aerial photos taken by cameras attached to kites and balloons. Now the technique is sometimes referred to as structure from motion in reference to a camera moving through the scene. Until a few years ago, however, it was not a viable tool for gleaning information about forests.

"We could not use it well before because we didn't have digital photography, and then once we had digital photos, we didn't have processing power. This technology likes big powerful computers," Gatzliolis explains.

Gatzliolis's primary interest with photogrammetry has been in developing a robust workflow that may make it a feasible tool when collecting data in the forest. He and his colleague Nick Strigul, with Washington State University (WSU), envision a not-too-distant future when field crews may carry a preprogrammed drone outfitted with photogrammetry equipment in their pack and deploy it to collect additional information that will complement manual data collection. "It will be a breakthrough in forest inventory," says

Strigul: "The information we can get will really enrich our understanding of forests because we can see changes not only in trees' [diameter at breast height] but in how trees grow in 3-D."

But with any new technology, first it's a matter of getting it to work reliably for research purposes, then it's a matter of deploying it as a reliable tool that others can use with minimal effort and get consistently accurate results. That's what the researchers are working on now.

Developing Protocols

When Gatzliolis and his colleagues first began experimenting with the utility of photogrammetry for forest measurements, no protocols existed for collecting forest data with this technique. So, the team set out to develop protocols for using photogrammetry below the tree canopy in which the cameras are directed at oblique or horizontal angles to the ground.

This usage sets it apart from LiDAR (light detection and ranging), another remote sensing tool, that directs 100,000 or more pulses of light per second toward the ground. When the light pulse hits something—a branch, a rock, the ground—it bounces back up, becoming a measurement. The resulting point cloud data can be used to produce a 3-dimensional representation of structures. However, when flown over a forest, most of the points tend to be positioned near or at the top of the tree canopy. "LiDAR is very good at describing from above, but it cannot be used as well to consistently describe with acceptable accuracy anything that is lying on the ground or standing vertically," Gatzliolis, says. This poses a problem when the goal is measuring tree stems or down wood.

The researchers built a custom drone outfitted with a Web camera that provided a stream of images for real-time processing. A key

Purpose of PNW Science Findings

To provide scientific information to people who make and influence decisions about managing land.

PNW Science Findings is published monthly by:

Pacific Northwest Research Station
USDA Forest Service
P.O. Box 3890
Portland, Oregon 97208

Send new subscription and change of address information to:

pnw_pnwpubs@fs.fed.us

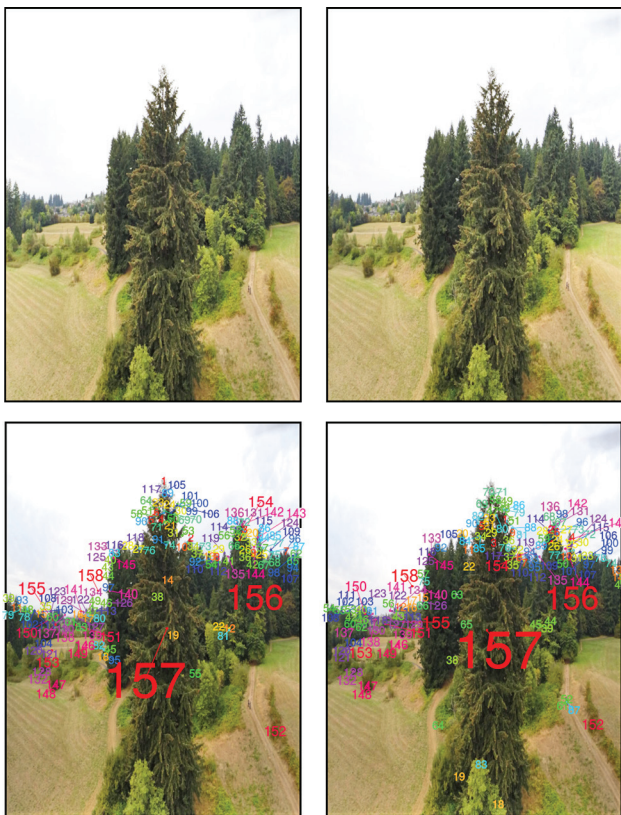
Rhonda Mazza, editor; rmazza@fs.fed.us
Cheryl Jennings, layout; cjennings@fs.fed.us

Science Findings is online at: <https://www.fs.fed.us/pnw/publications/scifi.shtml>

To receive this publication electronically, change your delivery preference here:

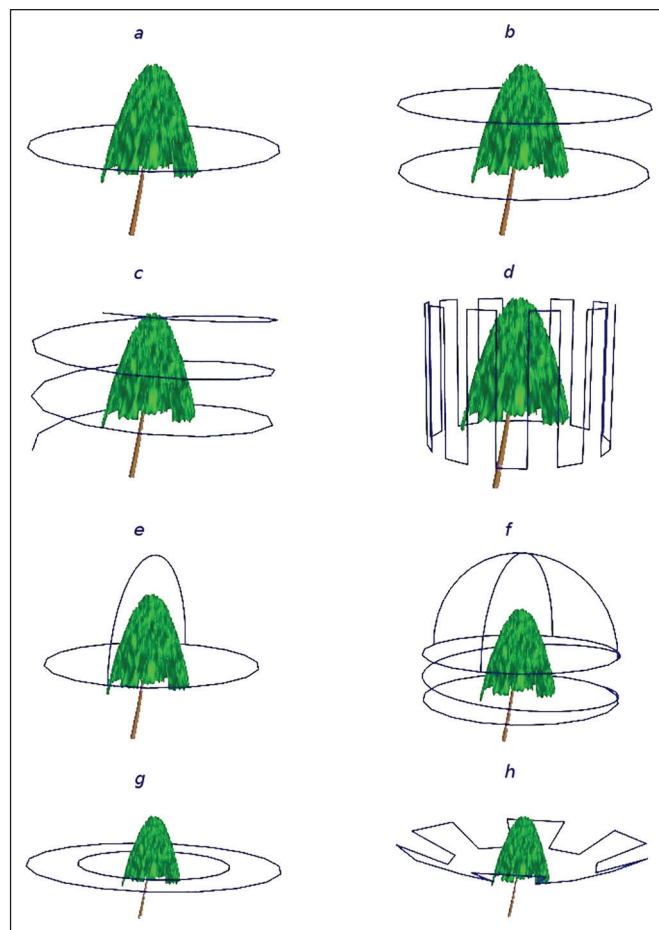
<https://www.fs.fed.us/pnw/publications/subscription.shtml>





Gatzliolis and Strigul 2015

Two images taken from slightly different vantage points (above) and the matching of 157 overlapping key points (below). This overlap in key point and the known position of the camera enables triangulation and, ultimately, a 3-dimensional reconstruction of the object.



Gatzliolis and Strigul 2015

The researchers programmed the drone with different flight trajectories and evaluated the most effective path. The spiral trajectory (c) produced the best results and was the most efficient in terms of battery use. They found that optimal reconstruction of the object needs a 70 percent overlapping field of view.

innovation was programming a stand-alone miniaturized computer that could be attached to the drone and process the stream of images during the flight. This enabled them to remedy a shortcoming in a common workflow that often resulted in an insufficient amount of overlap between images and, consequently, an incomplete reconstruction of the 3-dimensional image. Jean Liénard, a postdoctoral researcher at WSU and part of the study team, took the lead on this feature.

The team also tested different flight patterns for the drone to determine the most efficient way to capture data points from horizontal and oblique angles. They found the most efficient method to be an ascending spiral around the tree.

Programmable drones weren't available three years ago; so Andre Vogs, an engineer at Intel and part of the study team, set to work to add that feature to their custom drone. A programmed drone means the flight path is steady and predictable. It's key that the drone be at a nearly constant distance from the object being photographed or videoed, something that is impossible with a manually controlled drone no matter how steady the human

hand. The known position of the camera enables triangulation among key points present in multiple images.

Working below the forest canopy presents its own challenges for photogrammetry. It's a visually complex arena, with shadows and dappled lighting. A breeze moving a branch can lead to a blurred image, the sky in the background extends infinitely. Thin, flat leaves present another challenge. "The technology is designed for objects that have volume. Leaves create problems with the algorithms," Gatzliolis explains. On the plus side, "If it works in the woods, all the other manmade environments will be a piece of cake," he says.

Looking for a way to address some of these challenges, Gatzliolis turned to video games, specifically the high-quality graphics used in scenery. "I thought, 'someone made those trees,' so I contacted a computer game designer and asked, can you share a high-resolution image of a tree? The amount of data

behind it is mind boggling; they even simulate the effects of wind."

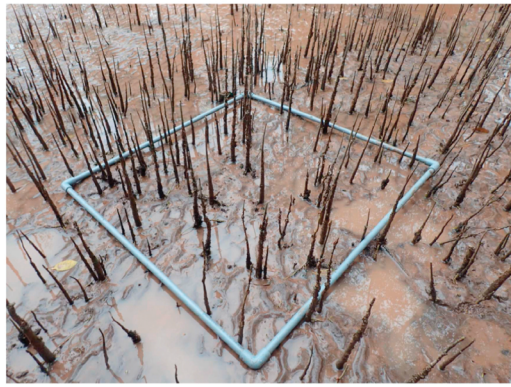
A computer-generated tree provides an efficient way to test one's method. Gatzliolis first has the computer take pictures of the virtual tree. He then processes the pictures to obtain a point cloud, converts the point cloud to estimates, and ultimately generates another rendition of the tree. "The beauty for me," explains Gatzliolis, "is that I have the end product and what I started from so I can compare the two. I can tell how many branches my method has missed, or how much volume [has been missed.]"

After extensive experimentation with different cameras, mission planning alternatives, processing software, and numerous procedural modifications, the researchers developed a workflow that can handle commonly encountered conditions and produce a detailed reconstruction of trees in 3-D.

Step 1. Image acquisition

Photographs are taken from numerous view points, with substantial overlap to allow matching of key points across images.

A typical photograph from a survey, with aerial roots inside a 1x1-meter frame.



Adapted from Liénard et al. 2016

using a standard digital camera. A single survey could be completed in about 5 minutes. They used a “freeware” package to construct the 3-dimensional point cloud and further processing with an open source software package. It took about 25 to 45 minutes in the office to generate the vegetation statistics from a set of photographs with minimal operator involvement. This is in contrast to several hours required through the traditional hand-count method.

No method is foolproof; the imagery needs to be captured on a windless day when the vegetation is still. In this case, the researchers also discovered barnacle growth on the roots could influence measurements. But overall, the method proved itself acceptably accurate, and faster and less expensive than hand counts.

From Trees to Forest

Gatzliolis and Strigul have sought multiple opportunities to further develop and test this technology. It's one thing to measure and model individual tree growth. Another layer of understanding is emerging as they use photogrammetry to document and create 3-dimensional reconstructions of individual trees self-organizing to become a forest. Posteruptum conditions on Mount St. Helens afford this opportunity to study primary succession and secondary succession in vegetation. Following the 1980 eruption, some areas of the blast zone were blanketed in sterile pumice, becoming a blank canvas for revegetation. In other areas, some shorter vegetation, from shrubs to tree seedlings, survived under the protection of lingering snow, biological legacies of the preeruption forest.

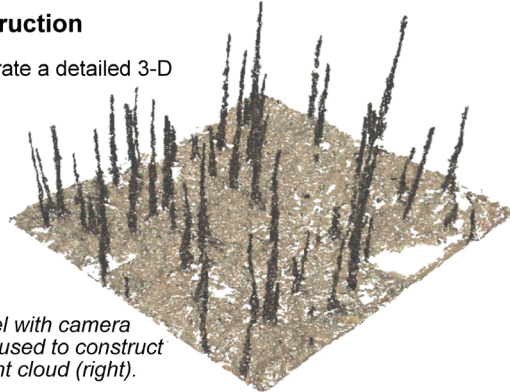
The researchers are working with ecologists who have been monitoring revegetation in long-term study plots since the eruption and using photogrammetry in these plots. “We are looking at metrics which people cannot assess manually—or it would take a long time—like volume of a whole plant,” says Strigul. By working in primary succession plots, “You can capture the details of spatial interactions, which would be hard to understand and quantify in a more developed system where trees have been interacting for generations.” The findings from this ongoing study will support models that project future conditions of a forest by accounting for spatially explicit processes such as competition for light, space, and other resources.

Step 2. 3-D Point cloud reconstruction

Structure from motion algorithms generate a detailed 3-D model of vegetation canopy.



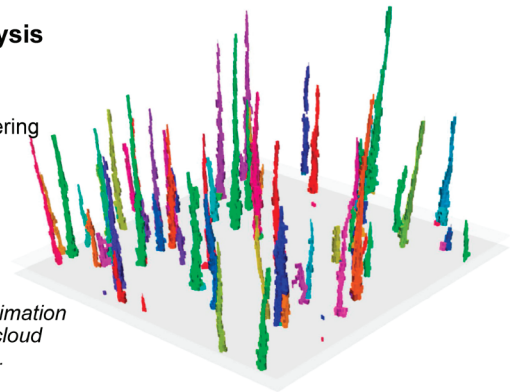
Sparse model with camera locations (left) is used to construct dense 3-D point cloud (right).



Step 3. Vegetation canopy analysis

Vertical profile is approximated into thin horizontal slices. For each slice, a clustering algorithm maps aerial root positions, and cross-sectional geometry of every aerial root is reconstructed.

Slice-sector approximation of the dense point cloud calculated in step 2.



The researchers used photogrammetry to analyze the vertical profile of aerial mangrove roots. This information is critical for modeling the ability of the mangroves to shelter the shoreline from waves and currents and to mitigate erosion.

Profile of a Mangrove

After hearing about their work with photogrammetry, Steve Henderson, a professor at WSU who studies environmental hydrodynamics, approached the team with a query about a research project involving mangroves. Specifically, he was interested in knowing the size and density of aboveground roots that shelter the coastline from erosion and can help reduce flooding. Gatzliolis recalls, “Steve asked us, ‘Can you tell me how many are there?’ Piece of cake, we said. ‘Can you tell me how tall they are?’ Yes.” That exchange

led to a study using photogrammetry to survey the aboveground roots of mangroves in Viet Nam. These aerial roots rise vertically from the wet ground, enabling the plant to intake more oxygen. The extent to which these roots can buffer the shore by dissipating wave energy depends in part on their size and density, so these measurements are crucial for modeling their sheltering effects.

The resulting study was the first to use photogrammetry to depict the full vertical profile of aquatic vegetation. Working at low tide, the researchers took imagery of the study plots by



Nick Strigul

The Mount St. Helens pumice plain. Researchers are using photogrammetry to monitor plant colonization following the 1980 volcanic eruption. The process they've developed enables them to determine plant volume and other metrics that would be extremely time consuming or impossible to gather manually.



Nick Strigul

An overhead (nadir) shot taken by an airborne camera of recolonizing vegetation on the Mount St. Helens pumice plain. With the information gained from this ongoing study, researchers plan to build a model that projects future conditions in a forest stand by accounting for spatially explicit processes such as competition for space, light, and other resources.

Snapshots in Time

With these developments in technology and processes, “We suddenly have the ability to describe the dimensionality for trees or objects in general in a cheap and efficient way. This wasn’t possible before,” says Gatzliolis. “Nature is too complex to describe with artificial measurements. This technology allows us instead of measuring certain dimensions of an object to have the whole object described in front of us.”

Hindsight, as the saying goes, is 20/20. It’s usually said with an air of regret, but in this case photogrammetry provides a way to capture information now and save it until needed. For example, Gatzliolis says, “What if 10 years from now someone says, ‘we want to measure this parameter’? You can’t go back in time and visit the plot, but you can have a snapshot in time of the plot. Perhaps in the future, parameters that emerged as important could be backtracked and computed using these snapshots as if we could travel back in time.”

“The noblest pleasure is the joy of understanding.”

—Leonardo da Vinci

Writer’s Profile

Rhonda Mazza is a science writer for the USDA Forest Service Pacific Northwest Research Station in Portland, Oregon. She can be reached via: rmazza@fs.fed.us



LAND MANAGEMENT IMPLICATIONS



- Rather than relying on species-specific equations to calculate tree volume from diameter at breast height, it is now possible to obtain similar but far more precise, near-ground-based measurements of object volume via integration of the object’s 3-dimensional representation.
- Managers of commercial forests can use photogrammetry (structure from motion) field-generated information in models that operate on remotely sensed data to assess the distribution and attributes of forests over large areas.
- The composition and distribution of natural resources often exhibits local variability that defies conventions. Established field data collection protocols are sometimes unable to handle certain conditions or fail to meet established precision levels. This variant of photogrammetry is capable of handling very complex vegetation forms.

For Further Reading

Gatzliolis, D.; Lienard, J.F.; Vogs, A.; Strigul, N.S. 2015. 3D tree dimensionality assessment using photogrammetry and small unmanned aerial vehicles. *PIOS ONE*. 10(9): e0137765. doi:10.1371/journal.pone.0137765.

Liénard, J.F.; Vogs, A.; Gatzliolis, D.; Strigul, N.S. 2016. Embedded, real-time UAV control for improved, image-based 3D scene reconstruction. *Measurement*. 81: 264–269. doi:10.1016/j.measurement.2015.12.014. <https://www.treeseearch.fs.fed.us/pubs/53160>.

Liénard, J.; Lynn, K.; Strigul, N.S. [et al.]. 2016. Efficient three-dimensional reconstruction of aquatic vegetation geometry: estimating morphological parameters influencing hydrodynamic drag. *Estuarine, Coastal, and Shelf Sciences*. 178: 77–85. <https://doi.org/10.1016/j.ecss.2016.05.011>.

Probst, A.; Gatzliolis, D.; Strigul, N. 2018.

Intercomparison of photogrammetry software for three-dimensional vegetation modelling. *Royal Society Open Science*. 5: 172192. doi:10.1098/rsos.172192.

Strigul, N.S.; Gatzliolis, D.; Liénard, J.F.; Vogs, A. 2015. Complementing forest inventory data with information from unmanned aerial vehicle imagery and photogrammetry. In: Stanton, S.M.; Christensen, G.A., comps. *New directions in inventory techniques and applications*, Forest Inventory and Analysis symposium 2015. Gen. Tech. Rep. PNW-GTR-931. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 346–351. <https://www.fs.usda.gov/treesearch/pubs/50426>.



PRSRT STD
US POSTAGE
PAID
PORTLAND OR
PERMIT N0 G-40

U.S. Department of Agriculture
Pacific Northwest Research Station
1220 SW Third Avenue
P.O. Box 3890
Portland, OR 97208-3890

Official Business
Penalty for Private Use, \$300

Scientist Profile



Demetrios Gatziolis is a research forester with the Pacific Northwest Research Station. He conducts research on applications of remote-sensing technologies, spatial modeling, systems analysis, and geographic information science. He specializes in the integration of remotely sensed and Forest Inventory and Analysis program data, and the development of inventory techniques. Gatziolis has a Ph.D. in forestry from Michigan State University.

Gatziolis can be reached at:

USDA Forest Service
Pacific Northwest Research Station
620 SW Main St., Suite 502
Portland, OR 97205

Phone: (503) 808-2038

E-mail: dgatziolis@fs.fed.us

Collaborators

Nikolay Strigul, Jean Liénard, and John Bishop, Washington State University, Vancouver, WA

Andre Vogs, Intel Corporation, Hillsboro, OR