Emerging Drone Technologies to Support Forest Management

Jamie Brookes introduces a range of digital tools that can be used in forest management and concludes with a 'do-it-yourself' challenge!

When completing a jigsaw puzzle, what do you use to help you figure out the context and layout of the overall scene before manipulating the puzzle pieces? *The picture on the box*.

Drone scans provide *the picture on the box* for forests. I have worked with a range of stakeholders – from community woodland groups to national agencies – and this foundational benefit of drone scans is highlighted time and time again. It provides a detailed, contextual backdrop against which forest management tasks can be identified, planned, and monitored.

Are you writing a management plan? Need to refresh old compartment maps? Identifying accurate areas or fencing lengths for grant applications? Identifying the spread of invasives? Checking for variation in crop performance? Identifying and evidencing the condition of ash? Identifying hydrological features underneath mature woodland? All these land management questions – and infinitely more – are aided with a drone scan.

> "Drone scans provide the picture on the box for forests."

My view is that the technology is mature, powerful, yet simple enough to be rolled out into everyday forest management practice. Make no mistake, I believe drones are a tool – in the same way a hammer is a tool. We do not view a building as the sole product of a hammer, and we should not hope to manage a forest solely with a drone.

In this article, I want to share some of my personal thoughts on drones in today's forestry, explain the main technologies in use today and discuss how automated data processing is evolving into the future. We'll first look at three technologies underpinning drone use today: Photogrammetry, Multispectral Imaging, and Light Detection and Ranging (LiDAR).

Photogrammetry

Photogrammetry is the process of stitching hundreds – or many thousands – of overlapping photographs together to create an accurate and representative three-dimensional model of any subject, such as forests. When captured well, this reconstruction allows us to digitally measure accurate distances, heights, visible colours, infrared and thermal reflectivity and more (Iglhaut et al., 2019).

Photogrammetry is the only method to produce the *picture on the box* discussed in the introduction. This process outputs a single high-resolution site-wide photo, covering all the area of interest (Figure 1). We call this stitched photo a 'georeferenced orthomosaic'. 'Georeferenced' means it is aligned spatially to the Earth's surface, 'ortho' means to remove distortion, and 'mosaic' being an image made of many smaller ones. To give a sense of scale, my largest drone scan stitched into a single orthomosaic covers 2,400 hectares!

As the orthomosaic image is referenced accurately to the Earth's surface, it can be loaded into mapping software and displayed as a base layer under normal forestry data such as compartment boundaries. Imagine Google Maps, but much, much clearer. This lets us examine the whole

forest from a desk, a vehicle, or while exploring the site itself – a forest in your pocket.

At this point, I'd like to offer an opinion. From my many conversations on this subject, I've found people have a slight tendency to rush towards the computer-generated results later in the process. I feel this is a potential folly. Humans already have an inbuilt processing architecture to analyse and understand photographs – never mind AI, we have two eyes!

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We can rapidly and intuitively pick up an astonishing amount of information from high-resolution images – and while it makes sense to ask the computer to perform tasks such as counting individual trees, the human mind is adept at identifying qualitative information. Just like the apprentice picking up their tree ID skills, there is a technique and skillset to interpreting the orthomosaic – and we can develop this skillset just like any other. I feel it will be a worthwhile skill for all forest professionals and stakeholders to acquire going forward.

Multispectral imaging

Multispectral imaging also uses photos. However, the sensors are finely tuned to capture only narrow bands of light, some not visible to the human eye. The technology promises an opportunity to enhance our understanding of vegetation through an ability to visualise chlorophyll reflectance in leaves and indirectly quantify it (Figure 2). This works quite well in situations where there is a very high level of uniformity and differences in chlorophyll content stand out quite clearly. For mixed forests, it is a little more involved.

In some situations, multispectral information can be a real help. It is great for picking out ash dieback, as



Figure 1. Example orthomosaic output. The detail is fine enough to review individual trees, yet covers many hectares. Zoomable on screens!

the exposed ash branches clearly show up at a different value to the green leaves. I have also had reasonable success in one forest delineating Corsican pine from other tree species. However, I have not found that all tree species return unique reflectance values, nor that it highlights tree stress before it can be seen with visible light. Some success has been had using multispectral imaging in a 'time series' study – remeasuring the site several times throughout a season to use differences in foliation as a marker of species (Forestry Commission, 2023).

I have only performed multispectral scans using a DJI Mavic 3 Multispectral drone, and so there may be limitations to that platform which do not appear on more sophisticated units. I would advise, however, that if you are to commission a survey including multispectral imaging, you have a plan for how to exploit the information in advance.

Light detection and ranging (LiDAR)

This technology employs use of *active* measurement, meaning it emits energy to function, as opposed to passively recording it, as is the case with cameras. LiDAR-carrying drones are much bigger than everyday camera drones and usually require a two-person team to use them in forests.

In LiDAR, laser pulses are emitted from the LiDAR unit, which also has sensitive receptors to detect reflections. A popular LiDAR sensor, the DJI L2, emits 240,000 pulses every second.

We know the speed of light and the angle the laser pulse was emitted, and so, when a pulse reflects or refracts off an object, we can determine its distance from and relative position to the sensor. Using enhanced GPS techniques (search for Real-Time Kinematic GPS), we also accurately know the position of the drone at any time, and as such, we can gather accurate measurements of the subject in 3D space.

LiDAR units can detect more than one reflection per laser pulse (we call these 'returns'). The L2 can detect up to five returns from a single emitted laser beam – meaning it could make up to 1.2 million measurements per second. While leaves obscure a camera's view of the understory, emitted laser pulses can penetrate very small gaps in

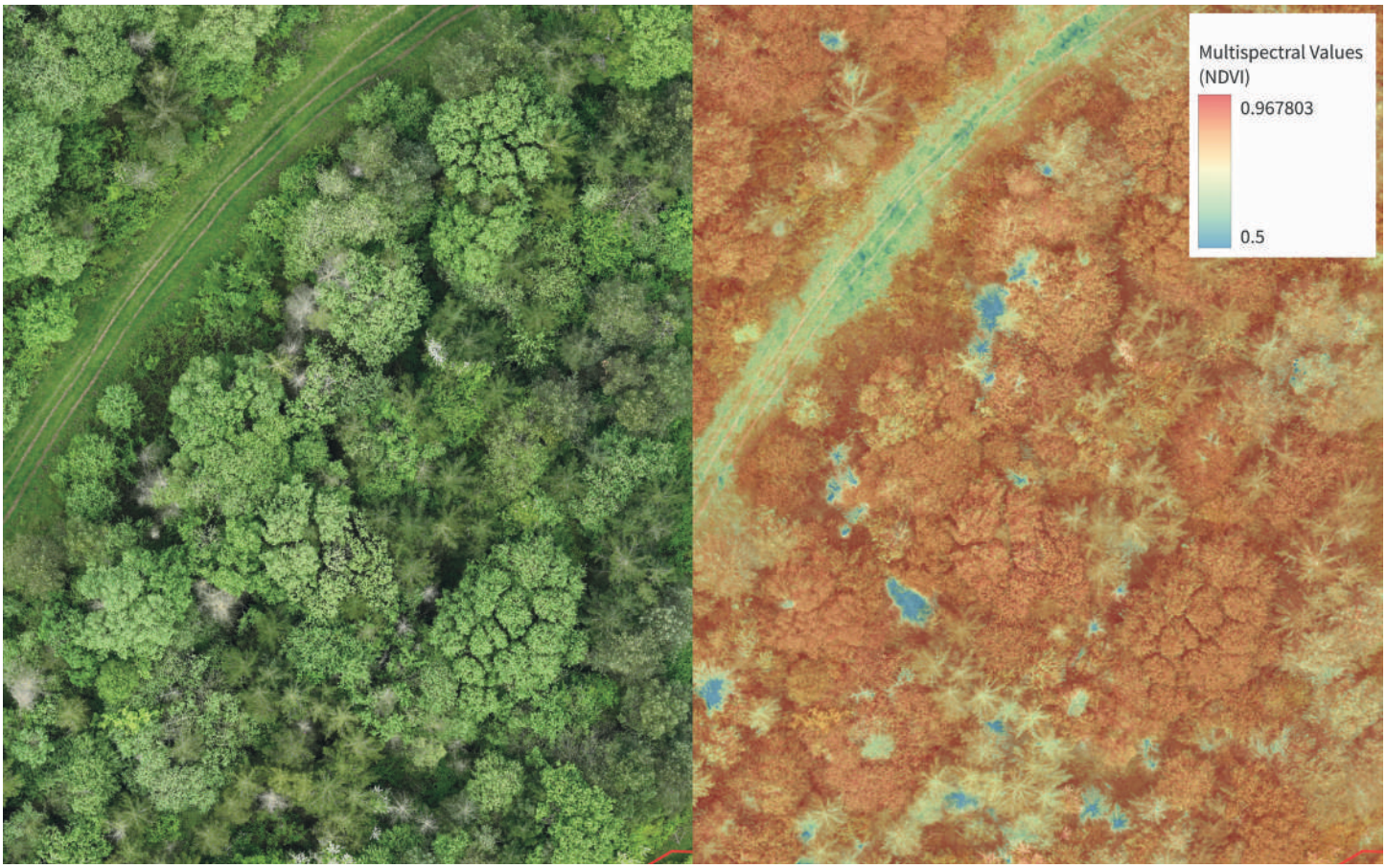


Figure 2. Visible light image (left) compared to visualised reflectance values from a multispectral scan (right). Red values indicate higher chlorophyll; blue values indicate lower chlorophyll.

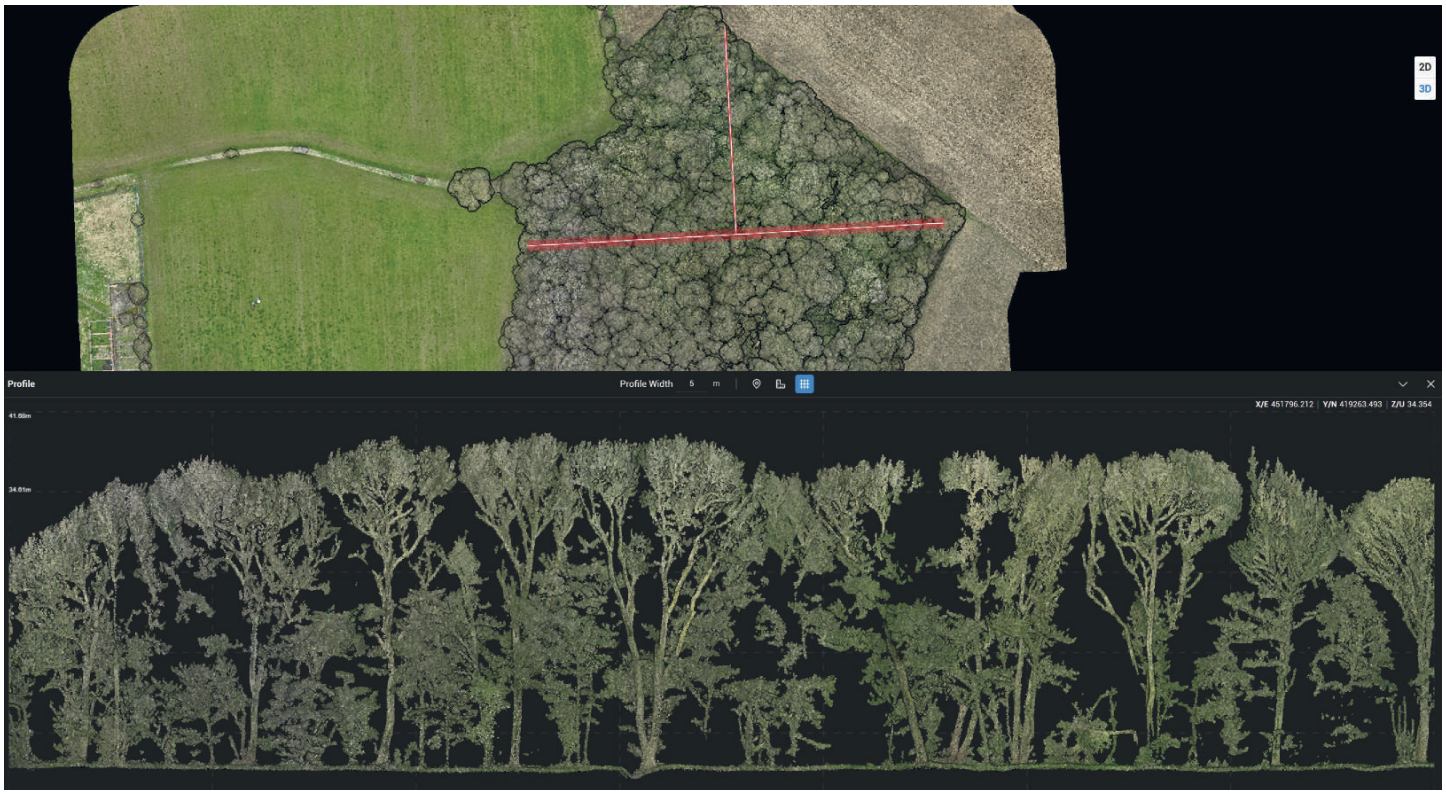


Figure 3. Cross-section slice of a LiDAR scan in an ash-dominated woodland in winter. Cross-section profile is 5 metres wide.

this layer of foliage, and the subsequent reflections allow measurements of under-canopy structure.

This is not magic. There is a limit to the LiDAR's ability to do this, and it comes from the variability of the subject. An ash-dominated native woodland may well have quite a thin canopy and allows more effective gathering of multiple returns and measurement of stem metrics. In contrast, I have found good measurements of mature yew tree stems to be difficult due to their dense foliage. The technology also struggles to penetrate dense ground cover, such as bracken.

LiDAR does not generate images. It produces a data type called a 'point cloud' (Figure 3). This is a collection of millions of individual points in space reconstructed from the light beam returns. While impressive, this data type is quite specialised, needing specific software and post-processing to generate accessible information for forest management.

Post-processing

Once we have collected our data, we enter the rapidly evolving world of computer analysis for forest management purposes, which we call post-processing. Using a variety of methods, we can ask the computer to start to analyse the data for us. A good starting point is 'individual tree delineation' – the process of splitting up the mass of data into separate locations of treetops and outlines of individual tree canopies (Figure 4).

Imagine you were to drape a very large tablecloth over a forest. You would see a smooth upper surface with 'lumps and bumps' caused by the treetops. We can visualise this upper surface in mapping software, and we call it a 'canopy height map' (Figure 4). In certain cases, we can ask a computer algorithm to analyse the canopy height map and indicate the location of individual treetops (Popescu and Wynne, 2004). The algorithm can then follow the fall in canopy height to edges where another canopy starts to rise, enabling modelling of crown diameters.

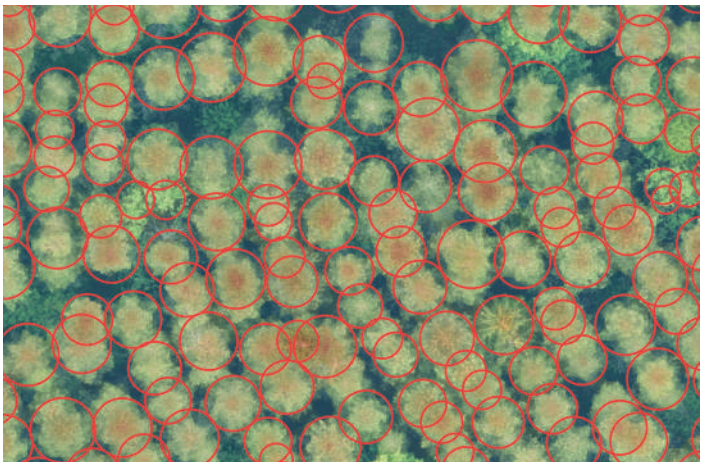


Figure 4. Canopy height map visualisation with individual tree delineation algorithm applied. In this visualisation, blue denotes ground and red denotes maximum height.

This works great for trees displaying strong apical dominance, such as conifers. However, broadleaves with wider canopies and multiple 'peaks' per canopy make applying this method more challenging, particularly in dense stands with a mix of species. This is not to say that it doesn't work at all, or that the height data for broadleaves is less reliable, it's just more difficult to get accurate tree delineation using this technique for these kinds of woodlands, as their upper surface is less regular.

One may turn to an emerging technique to accurately delineate these mixed woodlands – use of 'neural networks'. Neural networks are specific algorithms which process data in layers of interconnected steps, learning patterns by comparing inputs and outputs rather than following fixed rules. They underpin technologies such as ChatGPT and are colloquially known as 'AI'.

There are many types of neural network, and some perform 'image recognition' (Onishi and Ise, 2021), identifying complicated and specific patterns that are hard for humans to discern. Unlike the functionality of LiDAR units, there is an element of magic to this, in that we do not know exactly how they accomplish it. There are also many types of neural network algorithms, and they are evolving at a rapid pace. It looks likely that neural networks will become a dominant method for post-processing all manner of drone scan outputs in the near future.

"Drone scans have a place in everyday forest management."

Automatic mensuration

Once we have delineated our trees, we need to start gathering individual tree metrics, which we can then combine to form a stand-level understanding of volume. Traditionally, this involves sample plots and the critical measurement of diameter at breast height (DBH).

In some circumstances, such as recently thinned woodland conditions, we can reconstruct stem diameters using photogrammetry. In others, LiDAR has the advantage due to its penetrative ability and direct method of measurement (sensed reflections as opposed to computer reconstruction from photographs).

To give examples, here are three approaches to timber volume reconstruction from drone scan data, and it is for individuals to decide which they would like to use, and when. They increase in specificity, but also complexity and ultimately cost.

- *Top height + age → Yield Class*
  A quick and everyday method is to take the drone-measured top heights for any given tree and use that information (combined with a known species and age) to estimate Yield Class and look up the predicted volumes from the yield tables. We can do this cheaply with photogrammetry.

- *Sample plots + allometry → localised estimates of volume*
  Yield tables are general and based on averages. To go further, we can incorporate traditional sample plot measurements in the target forest, including DBH. We then use those specific allometric relationships for the forest or stand under review. Using the same drone scan dataset, we can apply that predictive relationship to the known top heights or canopy diameters of all trees in the forest to produce local estimates of volume.

- *Direct stem measurement via LiDAR*
  The user can ask the computer to measure every stem's individual DBH and use that information to create a direct volume prediction. This approach usually requires very good LiDAR data and is difficult to apply in all situations – forests or woodlands with dense understory create noise in the data that must be cleaned so as not to skew the results. There is great interest in developing algorithms to analyse the outputs of LiDAR in this situation to achieve this goal, but I have not yet seen an accessible, turn-key solution.

Automatic tree species identification

Trees and forests are not a static, reliable target. There is huge variability in the natural world, and the forests show this in their canopy. The factors which affect forest data collection include time of day, time of year, recent climate conditions (e.g. drought), weather conditions during the scan, tree stress, age, and many more. We have seen this past year that trees reacted differently to the long dry spell depending on the local geological and hydrological conditions present around them. This results in variability of how an individual tree species presents, and the challenge is to find some identifiable metric common to all trees of a particular type (Figure 5).

Two popular approaches to automated species ID involve neural networks performing image recognition. One



Figure 5. Variation in forest presentation. Left panel: April 2025 cloudy conditions. Right panel: July 2025 sunny conditions. This shows the effect of time of year and conditions on drone scan outputs. Slight-to-medium cloudy conditions are preferred.

approach is to gather and pre-train a network on a large set of known, human-annotated examples (Mauri et al., 2017). The strength of the output in this instance is dependent on the quality of the training dataset, and whether it covers all your target species.

Another approach involves highlighting known examples of a species in a specific scan output and tasking the computer to search for similar examples across the same dataset. This benefits from using examples specific to an exact time and environmental condition but requires the user to be able to manually define multiple examples of all desired species in the area of interest before the network can perform its search.

Do it yourself!

You can try post-processing at home. Free, low-resolution LiDAR coverage exists for England and Wales. Scotland and Northern Ireland have some LiDAR coverage, but the coverage is incomplete. The latest data was captured nearly four years ago, and at one measurement per square metre (typically), it is too coarse to reconstruct forests in detail. However, one can use this to experiment with remote sensing. The data from these countries can be accessed and downloaded from the following websites:

- England: https://environment.data.gov.uk/survey.
- Scotland: https://remotesensingdata.gov.scot/data#/list.
- Wales: https://datamap.gov.wales/maps/lidar-viewer/.
- Northern Ireland: https://admin.opendatani.gov.uk/dataset/?q=lidar.

These LiDAR datasets are typically divided into smaller regions which can be downloaded individually. One should choose an area of interest and download both the Digital Terrain Model (DTM – a grid of terrain surface heights with above-surface features such as trees removed) and Digital Surface Model (DSM – the terrain surface with above-ground features such as trees included).

Then, download a copy of QGIS. This is a free Geographic Information System (GIS) software which can load and manipulate the accessed LiDAR data. Load in your downloaded DTM and DSM. Use the ‘raster calculator’ function to subtract the DTM layer from the DSM layer, and you are left with resultant heights of all above-ground

features – including trees! You have now generated a 'canopy height map'. There are numerous open-source packages and computer algorithms available to start to analyse your canopy height map. As an initial suggestion, you may wish to visit resources like openforestobservatory.org to read further.

At least in England, the data is primarily captured during the winter. This results in a 'messy' canopy surface output for broadleaved trees with no consistent and smooth representation of the canopies' upper surface, due to the chaotic reflections from exposed branches in the canopy.

In a previous *QJF* article, Richard Pumphrey details an excellent case study of this type of data (Pumphrey, 2023). In the article, he notes that the Environment Agency's LiDAR measurements in Shrawley Wood "was consistently around 2 m below the actual height, judged by sample trees measured directly".

To finish with a short conclusion, I think drone scans have a place in everyday forest management. There are aspects of the computer analysis still in development, but the base outputs of orthomosaic images and canopy height maps deliver real insight today. The Institute of Chartered Foresters has recently decided to add these topics to its competency framework, a testament to their burgeoning establishment in today's practice. If you're considering whether drone scans are right for you (Figure 6), would like help with any of the topics raised, or have questions on topics not covered, I'd love to hear from you.



Figure 6. RFS training course 'New Technology in Forestry', conducted September 2025.

Author's note:
Any software, tools, or external resources mentioned in this article are provided for informational purposes only. The author and the QJF do not endorse their safety, reliability, or suitability. Users should verify and use external data or code at their own risk.

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A former engineer, **Jamie Brookes** has been exploring woodlands digitally under the name Landscan UK. He performs photogrammetry and LiDAR scans, virtual reality productions, cartography and training. He delivered the recent RFS training day 'New Technology in Forestry' on this subject in September 2025.

Email: enquiries@landscan.co.uk