MOBILE LASER SCANNING IN FORESTS: MAPPING BENEATH THE CANOPY

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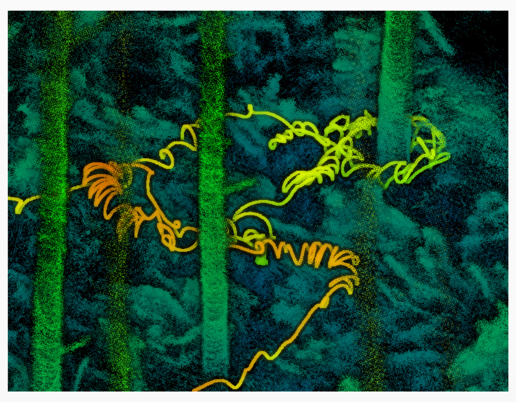
INTRODUCTION

Terrestrial laser scanning (**TLS**) has rapidly become an essential tool for accurate forest inventory as it facilitates collection of high-volume, high-precision spatial data. In recent years, handheld mobile laser scanners (**HMLS**) have emerged offering a cost- and time-efficient alternative. Yet to date, fewer than 10 studies have assessed this technology. In this project, one such HMLS sensor was assessed in terms of below-canopy, high-resolution, 3D forest mapping.

SLAM automatic positioning performed well, particularly in dense vegetation and where topography was complex. However TLS offered superior accuracy and precision. Only our TLS proved capable of obtaining reliable tree and crown heights.



Above-left: a photograph illustrating the author collecting data with a GeoSLAM ZEB-1 handheld laser scanner in one of his forest field plots.

Above-right: example ZEB-1 dataset showing a point cloud of the same area, depicting trees and brachiophyte (fern) undergrowth. The orange-yellow line is a 3D projection of the ZEB-1 survey trajectory, recorded during survey. In other words, the route taken while scanning the plot.

ABSTRACT

Forests are of critical importance in the **global carbon cycle**. There are numerous international projects which seek to better-understand the role forests play in carbon storage and emission. However, many rely on relatively-coarse (10 to 20 m pixel size) **remote sensing**-derived datasets reporting metrics at plot, rather than tree, level. Therefore precision is sacrificed in favour of wall-to-wall coverage.

This study aimed to explore the physical forest structure underlying these pixels with particular focus on characteristics otherwise hidden from optical sensors by canopy and crown. To measure structure, a variety of terrestrial (**TLS**) and handheld mobile **laser scanners (HMLS)** were deployed.

HMLS technologies allow rapid, continuous collection of data and automated processing at the expense of precision and accuracy (RMSE = 0.03 m). Meanwhile, TLS techniques rely on individual scans acquired from static positions. TLS data require careful, manual post-processing to generate unified point clouds – but offer high precision and accuracy (RMSE = 0.005 m).

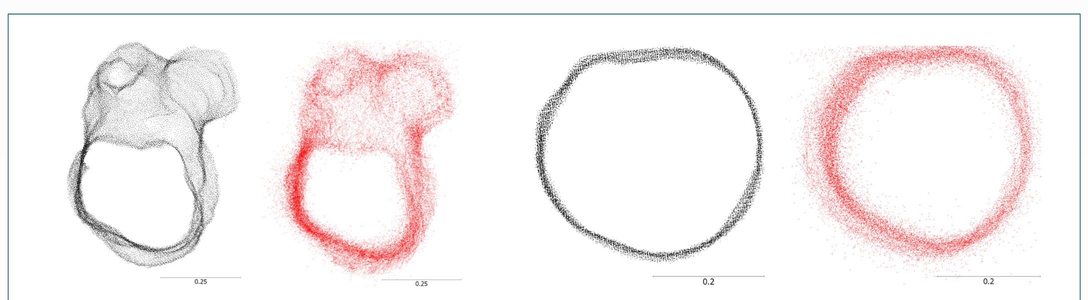
In the research presented here, TLS and HMLS point clouds were acquired concurrently. Data were **terrain-normalised**, then a semi-automated **segmentation** (**k-means nearest neighbour**) routine was applied. This assigned points to clusters, each associated with an individual tree. From these, variables such as DBH, tree height and crown geometry were extracted. These variables were then analysed with TLS-derived values considered as 'reference data'.

OBJECTIVE

A series of field plots were established in Victoria Park, Leicester. In each plot, a high-precision TLS survey was carried out using multiple scans from different points-of-view. This was followed with a series of HMLS scans using our ZEB-1 and cloud processing.

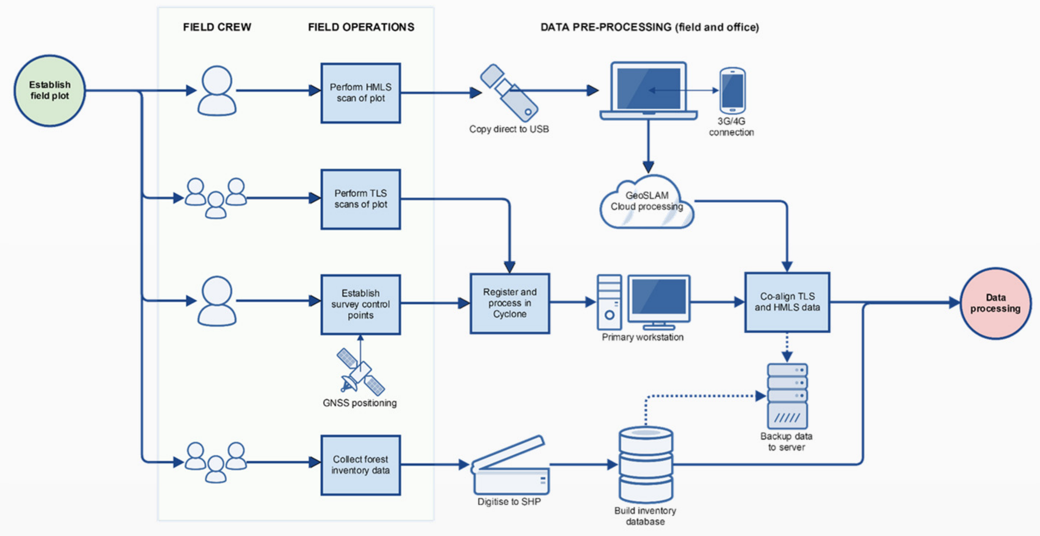
The aim was to compare performance of the HMLS sensor against a 'benchmark' dataset acquired using the TLS sensor. Specifically, we also assessed forestry parameters key to biomass mapping or otherwise under-represented in the literature.

Below: example trunk cross-section extracted from TLS (black) and HMLS (red) data acquired as part of this research.



METHODS

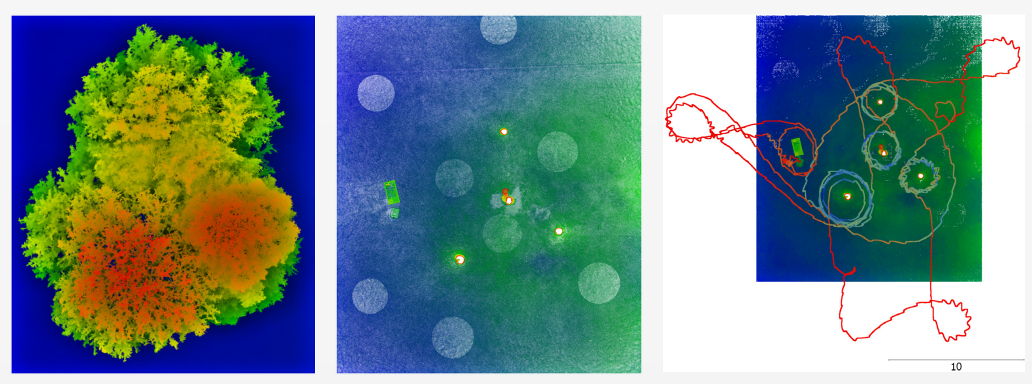
A series of field plots were established in Victoria Park, Leicester. In each plot, a high-precision TLS survey was carried out using multiple scans from different points-of-view. This was followed with a series of HMLS scans using our ZEB-1 and cloud processing.



TLS data was co-aligned (RMSE: 0.002 m) in *Leica Cyclone* and exported as a single .LAS point cloud. HMLS data was processed using *GeoSLAM Cloud*. The two datasets were co-registered in *CloudCompare* then imported, separately, into *3D Forest* where semi-automatic segmentation was conducted. This allowed individual tree diameter, height and canopy structure to be extracted. The data pipeline is illustrated above.

RESULTS

Here, we highlight some of our key findings through point cloud visualisations and analysis of tree structure. Below, the TLS 'reference' data is illustrated:

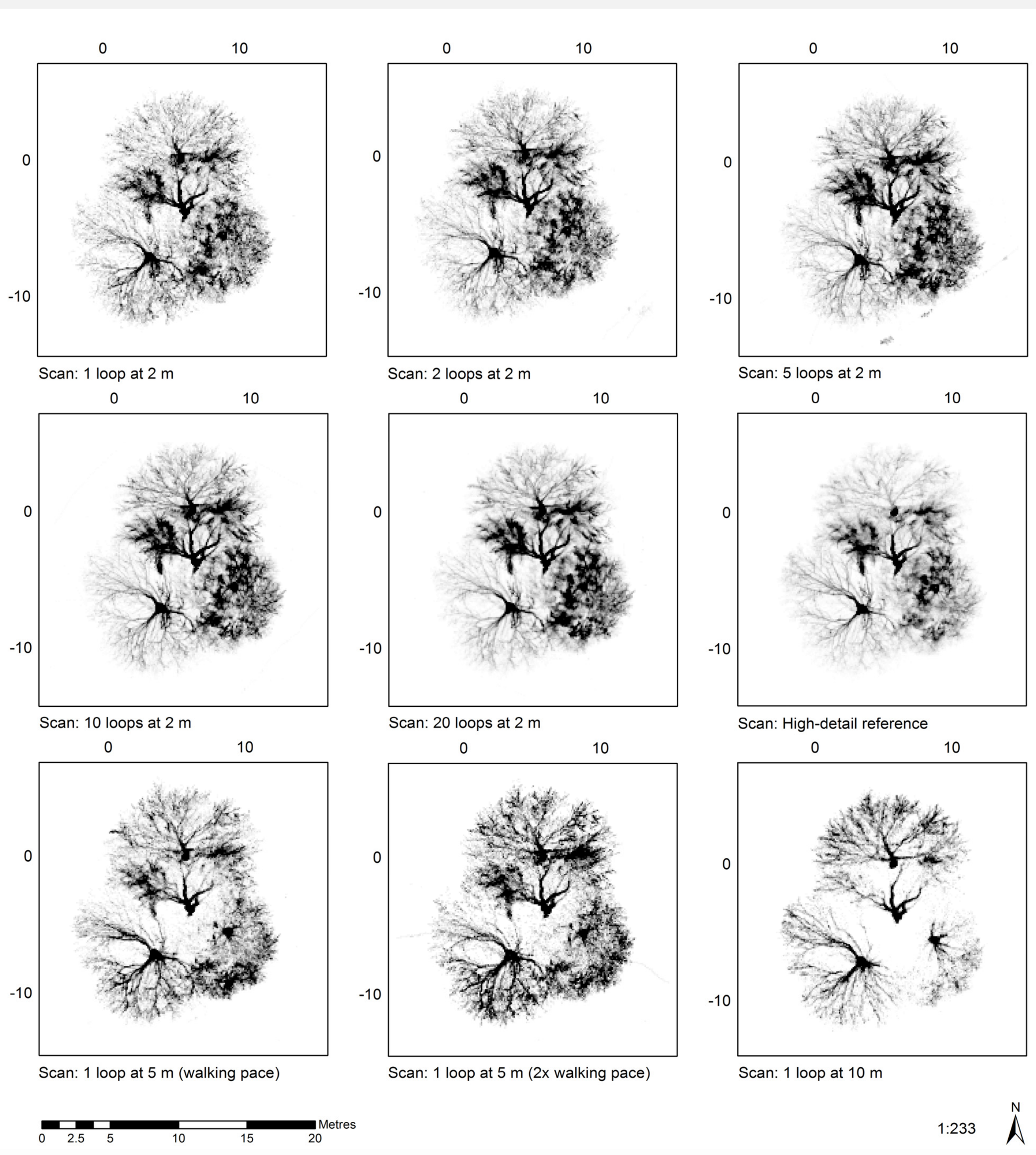


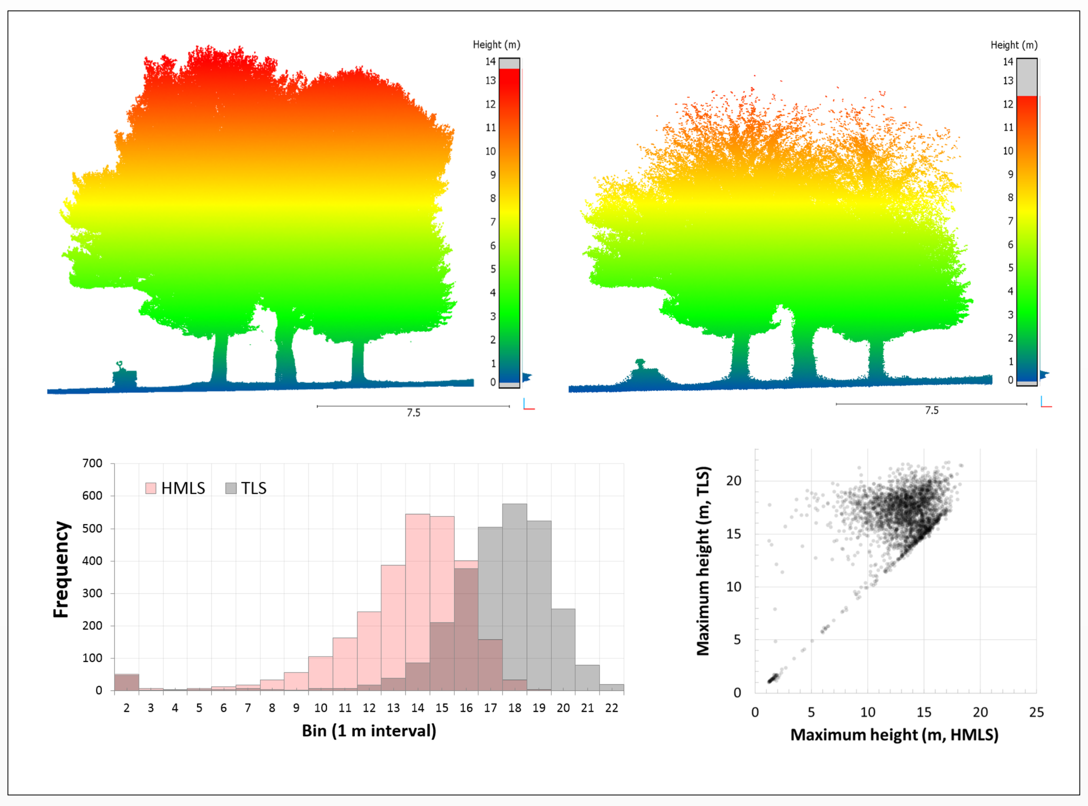
High-detail point cloud of 4 trees (**left**) in plan view and (**centre**) with the tree canopy data removed. Feint circles indicate the location of TLS scans around the tree trunks (bright spots). Zoomed-out image of the plot (**right**) showing HMLS trajectory (polyline) orbiting trees, the plot and adjacent objects.

TLS scanning for this plot took 2 hours, with 3 hours of processing. The HMLS scan took 11 minutes, and 11 minutes of cloud-based processing.

The same area of forest was then scanned using the GeoSLAM ZEB-1 HMLS sensor multiple times, each varying either (i) number of loops, (ii) distance of loop trajectory from the target trees or (iii) velocity of survey traverse.

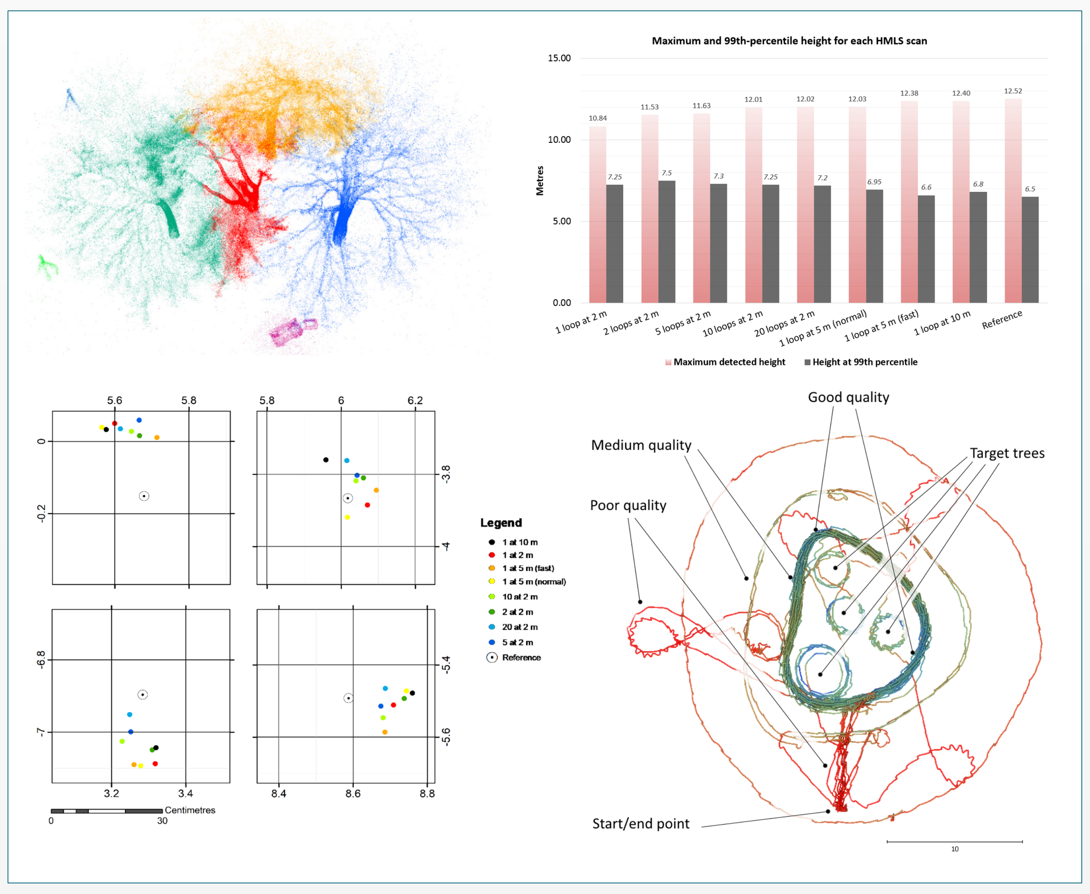
Below: aerial (plan) projections of HMLS data for each permutation assessed.





Above: side-by-side comparison of TLS (**top left**) and HMLS (**top right**) data in cross-section showing differences in detected height.

Below: results of HMLS segmentation (**top left**), height comparison (**top right**, showing 'useful' height at 99th percentile), relative detected tree centroids (**bottom left**) and HMLS scan quality (**bottom right**).



DISCUSSION

HMLS systems can play a key role in forest remote sensing, especially in dense areas of forest with complex topography and non-systematic structural geometry. The time savings associated with their swift operation (vs TLS) and cloud-based SLAM processing mean they are the best tool to quickly map tree position, diameter and forest topography.

However, HMLS systems are not well-suited to extracting tree and crown height. When combined with airborne data (e.g. airborne LiDAR or UAV structure from motion), HMLS data may prove a useful source of ground validation data.

CONCLUSION

HMLS systems are highly suited to forest scanning and related applications. However, we recommend:

- Scans are each limited to 30 minutes duration. Multiple scans can be co-registered to cover larger areas.
- The surveyor remains within 10 m of each object of interest (e.g. tree, shrub). We found 'useful' range is limited to 10 – 12 m
- Loops are regularly closed by rotating 360 degrees and having at least 3 m of overlap. Otherwise positioning quickly degrades
- Additional sensors (TLS; basic rangefinder) or third-party data (airborne LiDAR; UAV structure-from-motion) used to add accurate height data

AFFILIATION & ACKNOWLEDGEMENT

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This research is funded by a Central England NERC (Natural Environment Research Council) Training Alliance (CENTA) PhD studentship (grant number: 1503965) for which the authors are grateful. The research is further supported by the Satellite Applications Catapult as CASE (collaborative award in science and engineering) industry partner.

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