Measuring Forest Carbon with Mobile Phones

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INTRODUCTION

In order to create policy- and market-driven carbon credit schemes, we need reliable, accurate, and scalable technology to handle **monitoring, reporting, and verification (MRV)** for forest carbon projects.

We improve MRV of small-scale forest carbon sequestration projects by using **depth sensor-enabled mobile phones** to make forest inventories **more efficient without sacrificing accuracy.**

BACKGROUND

TRADITIONAL FOREST INVENTORY

Standardized, manual process:

- Map out plots with ribbon or rope; measure **tree diameter (Diameter at Breast Height, or DBH)** with a tape measure or calipers
- Use established **allometric equations** to relate measurable tree features to biomass and carbon storage

Cost and labor-intensive:

- Limits sample size
- Limits number of data points collected per tree
- Challenging to carry out in dense, diverse forests
- Heavy administrative burden on small-scale reforestation efforts and small research groups

TERRESTRIAL LASER SCANNING (TLS)

Generate point cloud of forest with surveying LiDAR

- Expensive (10-100K USD)
- Requires high degree of user expertise to operate as well as specialized software to interpret results

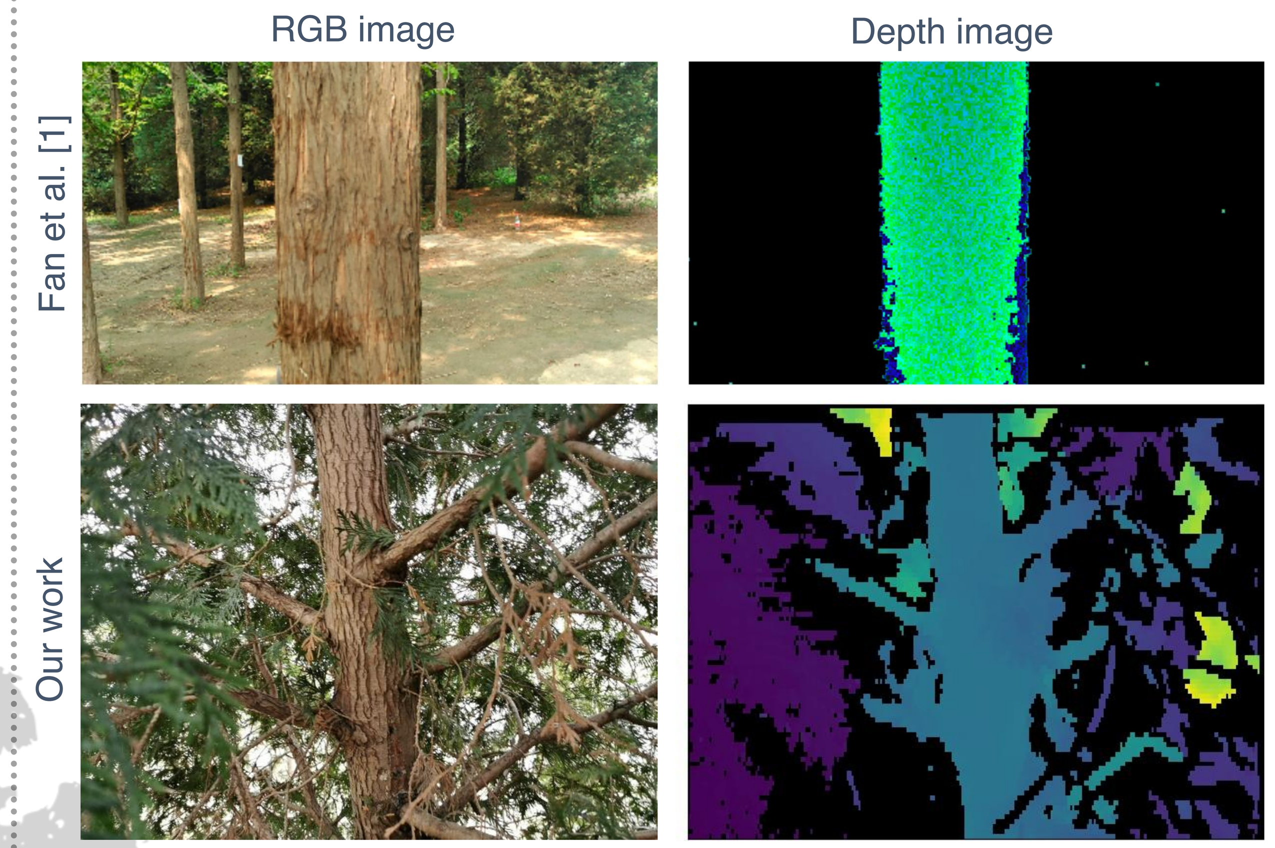
DEPTH SENSORS ON MOBILE PHONES

Time-of-flight sensors

- Emit infrared light and measure the time it takes to bounce back off of objects in the environment
- Increasingly popular on mobile phones for Augmented Reality applications (e.g. Huawei, Samsung, Apple, etc.)
- ~ 4 m range and mm accuracy
- Low-cost, portable

RELATED WORK

Prior work with mobile devices focuses on **timber and urban** forests, which have well-spaced trees with minimal undergrowth.
However, **naturally managed or unmanaged** forests are more important from a climate perspective and present a significantly different computational problem.



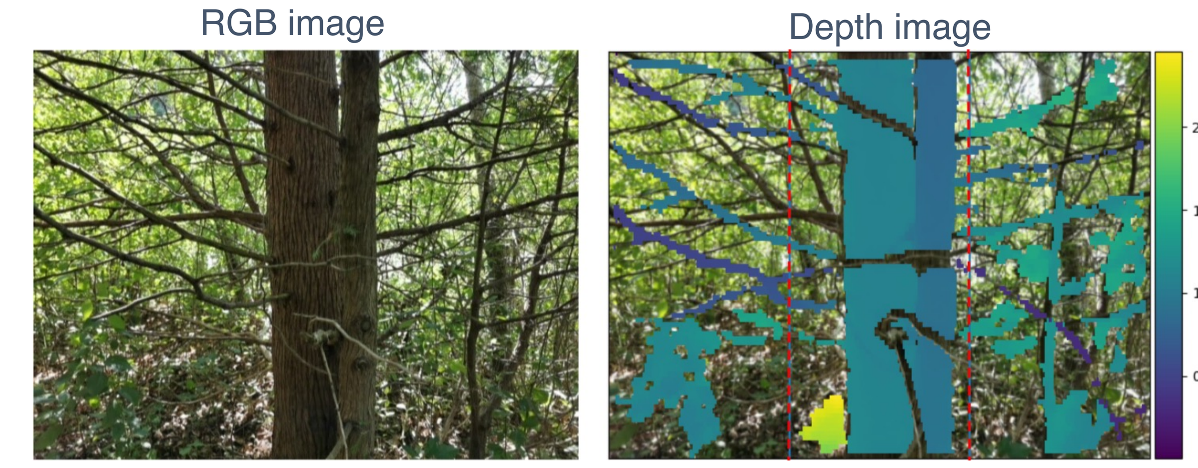
Capability	TLS	SfM	Tango	Katam	Our Work
High accuracy	✓	✓	✓	✗	✓
High detection rate	✓	✗	✓	✗	✓
Handles reasonable occlusions	✓	✓	✗	✗	✓
Accessible (low-cost, non-proprietary, easy and fast to use)	✗	✗	✓	✓	✓

TLS: Terrestrial Laser Scanning
SfM: Structure from Motion with Nikon camera (Piermattei et al. [2])
Tango: Google Tango (Fan et al. [1])
Katam: Industry app using video-based structure from motion [3]

CONTRIBUTIONS

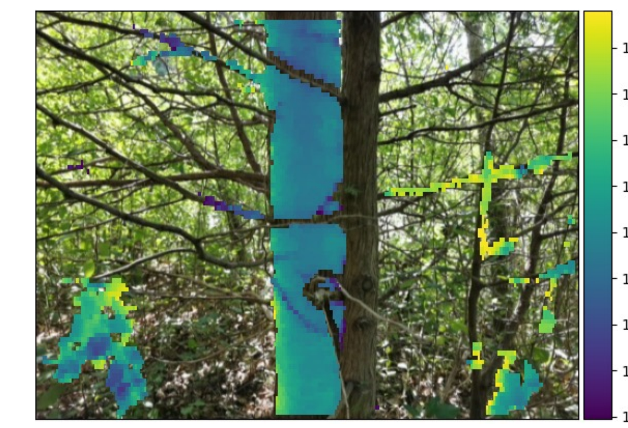
- We design an algorithm that exploits a low-cost smartphone time-of-flight sensor to estimate DBH from a single image, even with natural occlusion.
- We implement our design on a Huawei P30 Pro smartphone and demonstrate that it is efficient enough to perform in real-time, allowing user feedback.
- We evaluate our app in realistic forest settings and find that in a corpus of 55 sample tree images, it estimates DBH with an **RMSE of 4.1 cm (7.8%)**. These results are heavily affected by a single outlier; we analyze the improvements required to handle trees like this one; with its omission the RMSE drops to 2.5 cm (7.5%).
- We port our algorithm to Google's ARCore Depth API [5], which can acquire depth on mobile phones equipped only with a monocular camera. We offer suggestions for the improvement of ARCore to allow it to be usable for forest MRV.

DESIGN & IMPLEMENTATION

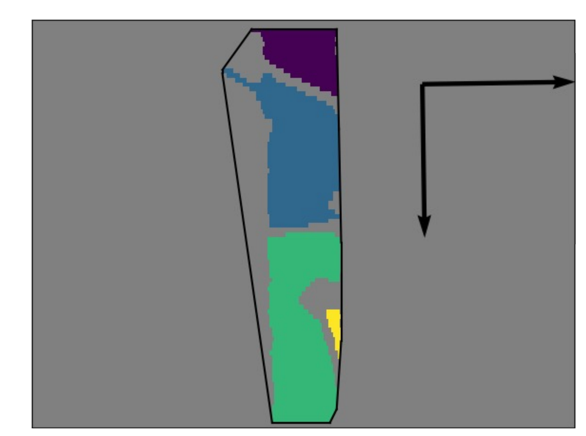


I. Approximate trunk depth

Approximate the trunk depth as the mode pixel depth in the center third of the image, and filter the image for pixels near that depth value.



II. Filter & orient trunk pixels

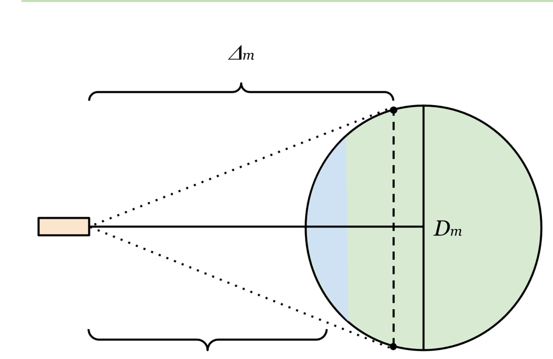


Search for a dense, oblong object in the image and use Principal Component Analysis [4] to identify its orientation. Rotate the image so that this object (the trunk) is vertical.

III. Identify trunk boundaries

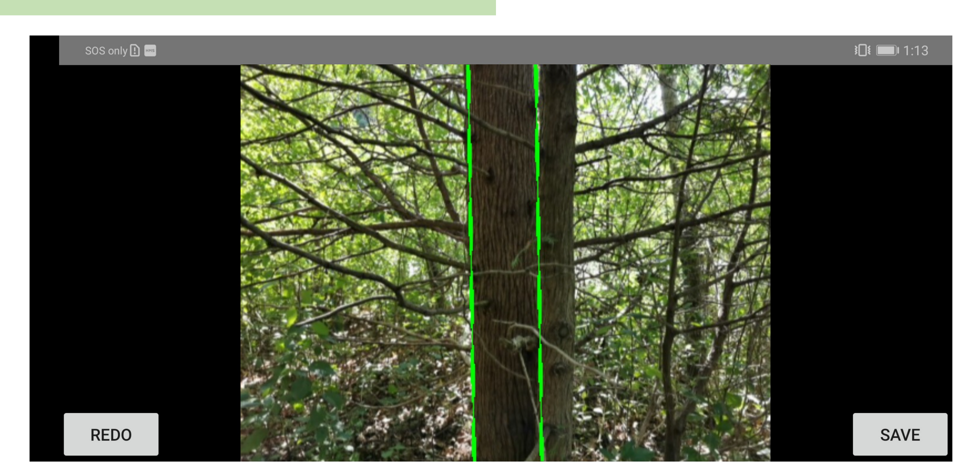
Iterate along vertical scanlines from the left and right of the image until the first line with a high ratio of likely trunk pixels to likely background pixels.

IV. Estimate trunk diameter



Robustly estimate DBH, accounting for parallax effects, occlusion and variability in the depth data, and the geometry of the trunk.

V. Confirm results with user

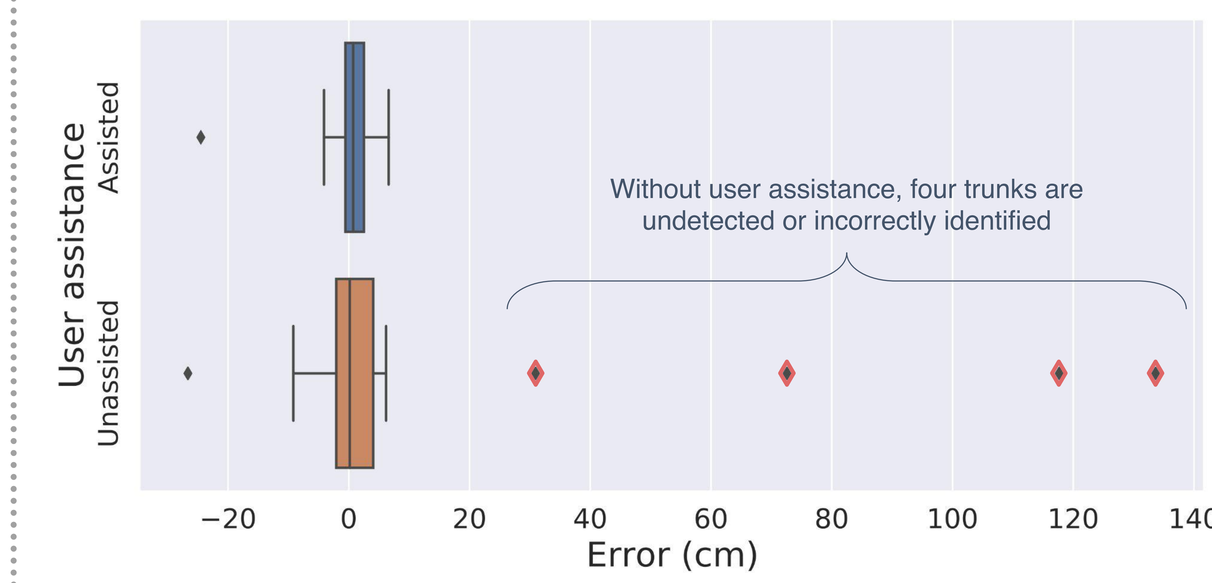


RESULTS

We evaluate our system in two naturally managed forests, measuring DBH in **complex conditions** with **high accuracy** (comparable to the results of prior work).

Dataset	No. Samples	RMSE (cm)	Bias (cm)	Mean % error
Summer	26	2.2	0.2	8.2
Winter	29	5.3	0.2	7.5
Combined	55	4.1	0.2	7.8

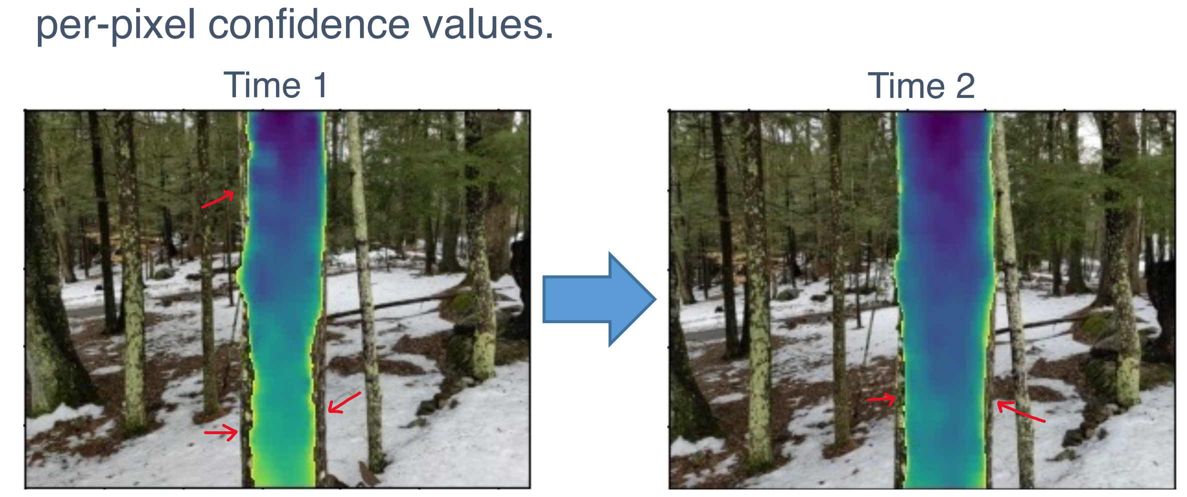
Our algorithm is **efficient**, running in **real-time** on the phone. This allows us to provide guidance to users and achieve **100% trunk detection** by asking for one-tap user confirmation.



Our system offers **3-4x speedup** over manual measurements.

ARCORE TESTING

ARCore [5] relies on a proprietary depth-from-motion algorithm using only a monocular camera and is compatible with many mobile phones. However, the data was of **insufficient quality for reliable DBH measurements**, with shadowy artifacts that did not correspond to real-world objects and changing results over time, especially near the tree edge, as the algorithm updated its depth estimates. It was difficult to work around these problems because the API did not provide per-pixel confidence values.



REFERENCES

[1] Fan, Y., et al. 2018. "Estimating Tree Position, Diameter at Breast Height, and Tree Height in Real-Time Using a Mobile Phone with RGB-D SLAM." *Remote Sensing* 10 (11): 1845.

[2] Piermattei, L., et al. 2019. "Terrestrial Structure from Motion Photogrammetry for Deriving Forest Inventory Data." *Remote Sensing* 11 (8): 950.

[3] Katam Technologies AB. 2020. "KATAM™ Forest." *Katam* (blog). November 27, 2020. https://www.katam.se/solutions/forest/.

[4] Rehman, H. and S. Lee. 2018. "Automatic Image Alignment Using Principal Component Analysis." *IEEE Access* 6: 72063–72.

[5] Du, R., et al. 2020. "DepthLab: Real-Time 3D Interaction with Depth Maps for Mobile Augmented Reality." In *Proceedings of the 33rd Annual ACM Symposium on User Interface Software and Technology*, 829–43. Virtual Event USA: ACM.

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