Poster: Measuring Forest Carbon with Mobile Phones

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1 ABSTRACT

Tree trunk diameter, currently measured during manual forest inventories, is a key input to tree carbon storage calculations. We design an app running on a smartphone equipped with a time-of-flight sensor that allows efficient, low-cost, and accurate measurement of trunk diameter, even in the face of natural leaf and branch occlusion. The algorithm runs in near real-time on the phone, allowing user interaction to improve the quality of the results. We evaluate the app in realistic settings and find that in a corpus of 55 sample tree images, it estimates trunk diameter with mean error of 7.8%.

2 INTRODUCTION

Carbon sequestration in trees plays a key role in decarbonizing the atmosphere and averting catastrophic climate change. In its 2018 report, the Intergovernmental Panel on Climate Change (IPCC) highlights that all pathways to limit global warming to 1.5°C rely on carbon dioxide removal, with most published plans incorporating forest carbon sequestration [8]. However, strategies to achieve these reforestation goals, whether through policy- or market-based incentives, face a technological challenge: they require monitoring, reporting, and verification (MRV) of forest plots *in situ* to evaluate the actual degree of sequestration achieved [4].

Current forest MRV uses a standardized, manual inventory process: mapping out sample plots with ribbon or rope, then using tape measures or calipers to find the diameter of each tree trunk in the plot [6]. This labour-intensive process has four negative consequences. First, it limits the *sample size*; thus only a tiny fraction of forested land has been sampled. Second, it limits the *number of data points* that can be collected per tree. Third, manual measurements are challenging to carry out in *tropical forests* where dense undergrowth surrounds trunks. Finally, it places a *heavy administrative burden* on small-scale reforestation efforts.

Terrestrial Laser Scanning (TLS) is used to address these problems, where specialized LiDAR instruments can create precise point clouds. However, these instruments are expensive ($10K-$200K USD), complex to operate, and bulky. In contrast, we explore using infrared time-of-flight (depth) sensors, along with a novel depth image segmentation algorithm, to measure tree-trunks in realistic settings. Specifically, we obtain RGB+depth images with a commodity smartphone, segment the image, that is, separate the trunk from the foreground and background, and then automatically measure the trunk diameter. We compare this to results obtained manually and find that our approach is much faster and has a small error.

Although we are not the first to use smartphones for forest plot inventories, prior attempts are designed for highly managed timber or urban forests, greatly simplifying the computational problem by assuming trees are well-spaced, brightly lit, and suffer minimal occlusion [2] [3]. In practice – particularly in the natural forest environments that carbon sequestration incentive schemes hope to foster – these conditions are unlikely to hold. In contrast, we are able to accurately measure tree trunk diameter (or Diameter at Breast Height, DBH) under complex field conditions.

3 SYSTEM REQUIREMENTS

We identify the following specific requirements for an automated mobile image-based inventory system in a natural forest environment:

- *Accessible*: The image-acquisition system should be low-cost, and the computational cost of the algorithm should be low as well. The system should be useable on multiple platforms accessible to a relatively non-specialized user.
- *Accurate:* The algorithm should be accurate.
- *Real-time*: The algorithm should complete with a low-enough delay that the user can correct errors in collected data immediately and seamlessly during fieldwork.
- *Single image*: The algorithm should not require multiple images of a tree from different vantage points, since these may significantly slow data collection and be difficult to obtain in dense or tropical forests.
- *Handles reasonable occlusion:* The algorithm should not assume that the trunk image is unoccluded.

4 RELATED WORK

In Table 1, we summarize the prior work in this field. Here, TLS refers to Terrestrial Laser Scanning; SfM to Structure-from-Motion on hundreds of camera images, as was proposed by Piermattei et al. [7]; Tango to the system designed by Fan et al. [3] that uses the depth sensor integrated with Google Tango's AR phone; and Katam to an industry app for timber forests [5]. In short, we are not aware of prior work that meets the above requirements.

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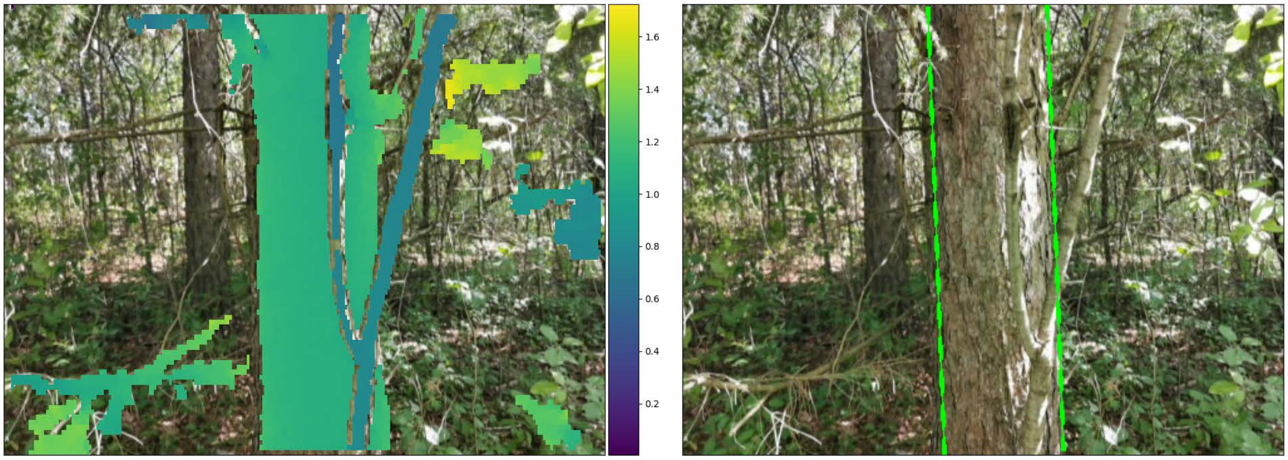

Figure 1: *Left:* RGB image with color-coded depth points (filtered and upsampled) overlaid. *Right:* RGB image with estimated trunk boundaries as found by our algorithm.

Table 1: Summary of Related Work

Capability	TLS	SfM	Tango	Katam	Our Work
Real-time	✗	✗	✓	✗	✓
Uses single image	✗	✗	✓	✗	✓
Handles occlusion	✓	✓	✗	✗	✓
Accessible	✗	✓	✗	✓	✓
Accurate	✓	✓	✓	✗	✓

5 DESIGN

We design a robust algorithm for a phone with a time-of-flight sensor that automatically identifies a tree trunk, segments the image to isolate the trunk's visible portions, and then estimates its diameter. We show a sample RGB+depth image and the identified trunk in Figure 1. We also port our algorithm to Google's ARCore [1], which does not require a time-of-flight sensor, but find that ARCore's continual refinement of its depth map causes tree trunks in the depth map to appear to "grow" over time. This prevents us from obtaining accurate measurements using ARCore.

6 CONTRIBUTIONS AND RESULTS

We evaluated our system in two different natural forests during summer and winter. Our contributions and results are as follows:

- We design an algorithm that exploits a low-cost smartphone time-of-flight sensor to estimate DBH from a single image, even with occlusion, and in poor lighting conditions.
- 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 of our algorithm to better handle trees like this one and note that with its omission the RMSE drops to 2.5 cm (7.5%).
- Recognizing that even time-of-flight sensors are somewhat specialized hardware, we port our algorithm to Google's ARCore Depth API [1], which can acquire depth on mobile phones equipped only with a monocular camera. We offer specific suggestions for the improvement of ARCore depth-from-motion to allow it to be usable in a forest MRV context.

7 CONCLUSION

We use smartphones equipped with depth sensors to estimate tree trunk diameter in forest plots with dense undergrowth, large trees, and natural occlusion. We believe that our work provides a promising direction for future research in the use of smartphone technology for the monitoring, reporting, and verification of forest carbon. Moreover, we believe that future research into mobile AR systems such as ARCore should consider scientific measurement in forests and other ecosystems as a primary use case.

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