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Leveraging Stereoscopic Vision to Estimate Tree Biophysical Parameters

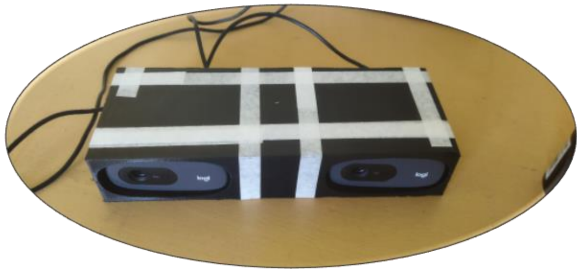
Cedric Kiplimo, Ciira Maina, Billy Okal

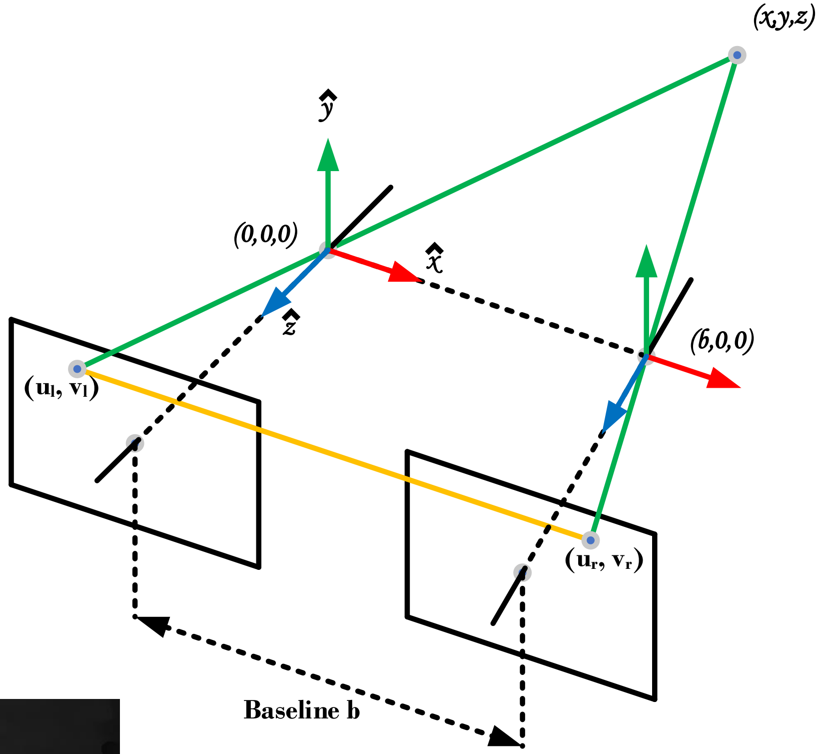
What is stereoscopic vision?

- Human vision
- Perception of 3D environment
- Disparity indicates depth
- Depth image

$$z = \frac{b \times f}{disparity} = \frac{b \times f}{u_l - u_r}$$

$$K = \begin{pmatrix} f_x & 0 & o_x \\ 0 & f_y & o_y \\ 0 & 0 & 1 \end{pmatrix}$$





R. Hartley and A. Zisserman, Multiple View Geometry in Computer Vision, Second ed., Cambridge University Press, 2003.

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Forest Inventory

- Data for assessment or analysis
- Diameter at breast height (DBH), height, basal area
- Timber, biomass, fire hazards
- Issues: cost, acquisition time, accuracy
- Philosophy: Begin small, KISS
- From depth image to DBH

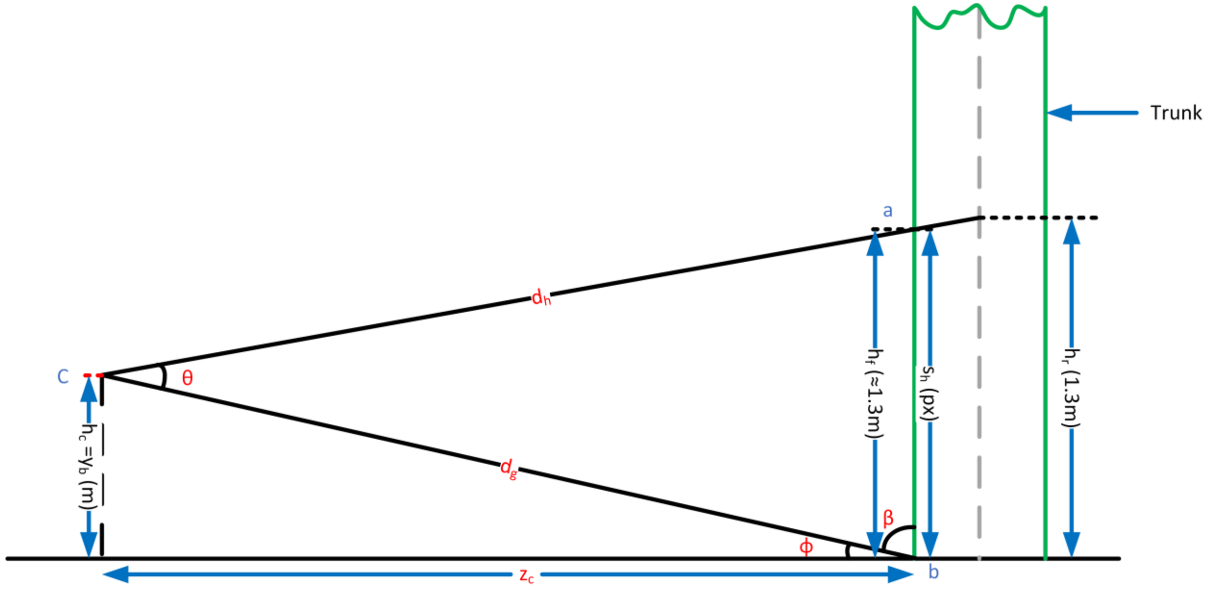
DBH Estimation Algorithm

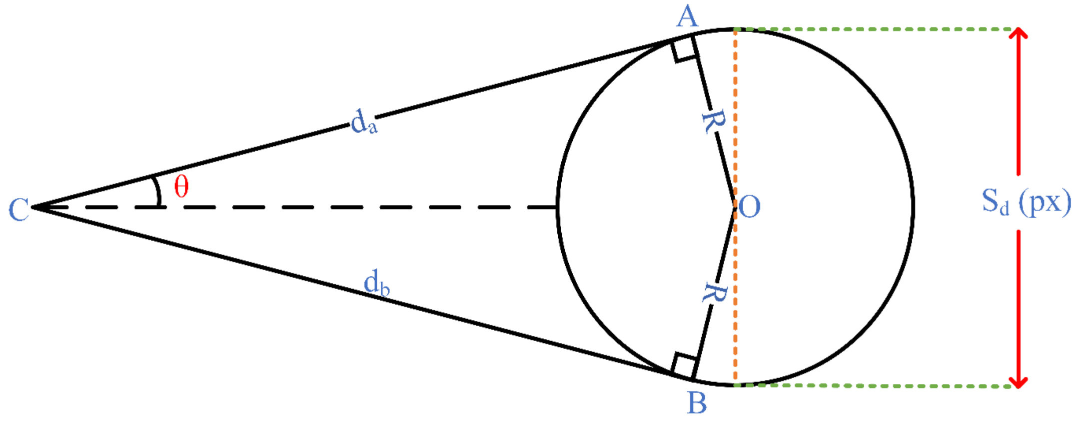
Inputs: Left & right images, mask, calibration parameters, reference DBH

Outputs: DBH value, Error

Steps

1. Compute and mask disparity image
2. Calculate row of breast height
3. Find disparities (intensities) of base b and breast height a pixels of interest
4. Find real-world distance to base and breast height pixels of interest
5. Find angles θ_1 and θ_2 based on their pixel span and FoV
6. Calculate DBH based on θ_2 and distance d_a as $D = 2d_a \tan\theta_2$





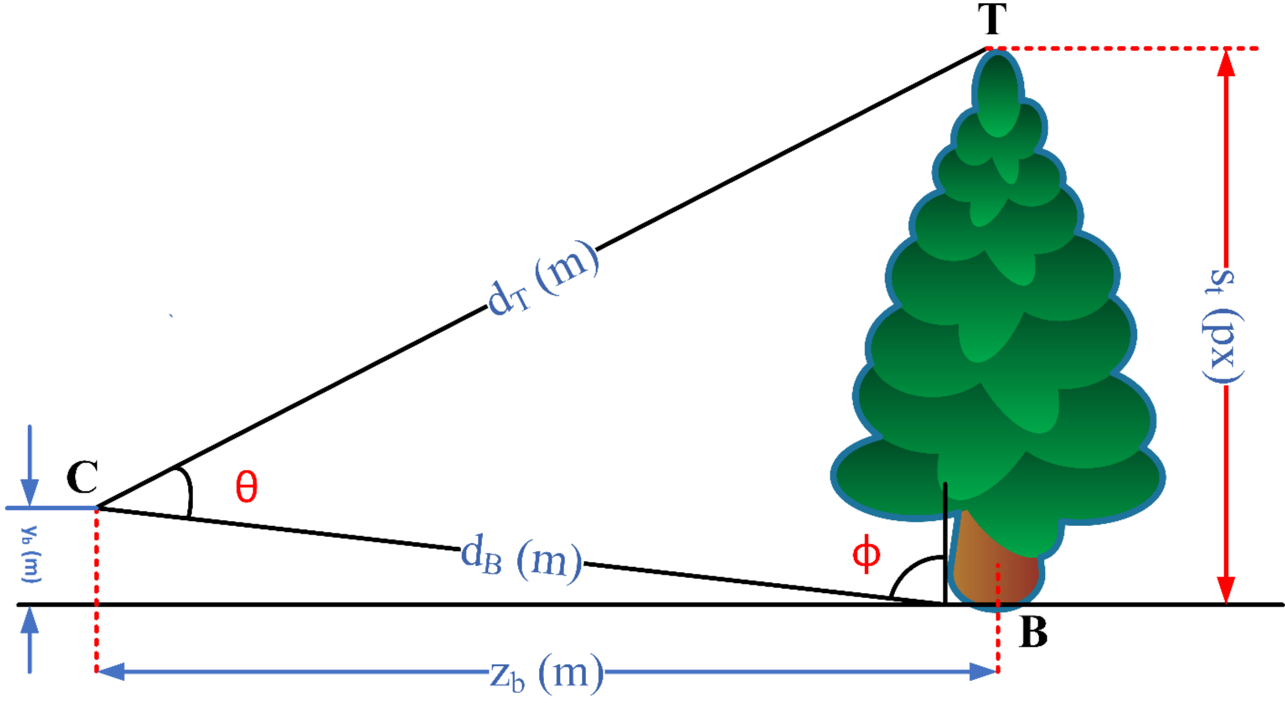
TH Estimation Algorithm

Inputs: Left & right images, mask, calibration parameters, reference TH

Outputs: TH value, Error

Steps

1. Compute and mask disparity image
2. Identify the base and top pixels of interest
3. Find the real-world distances to the base and top pixels of interest
4. Find angles θ and ϕ based on pixel span and FoV
5. Calculate TH as $TH = \frac{d_T \sin\theta}{\sin\phi}$



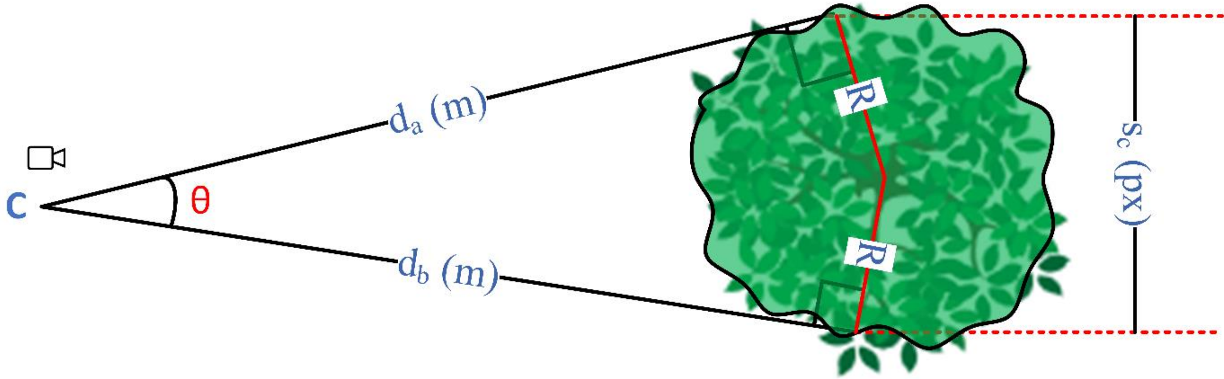
CD Estimation Algorithm

Inputs: Left & right images, mask, calibration parameters, reference CD

Outputs: CD value, Error

Steps

1. Compute and mask disparity image
2. Identify the crown edge pixels
3. Find the real-world distances of crown edge pixels
4. Find angle θ based on pixel span and FoV
5. Calculate CD as $CD = 2d_a \tan\frac{\theta}{2}$



Dealing with Presence of Peaks

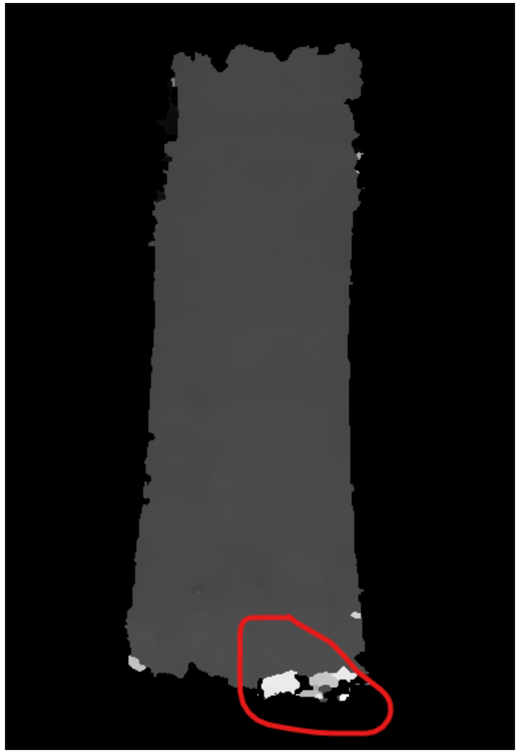
- Pixels of interest may be noisy
- Leads to inaccurate distance (and parameter) estimation
- Given a pixel of interest P in the i^{th} row of the disparity image, form a region of interest R such that:

$$R_{TH} = \{P_{i-20} \cup P_{i-19} \ldots \cup P_i\}, \quad P_x \neq 0$$

$$R_{CD} = \{P_{i+20} \cup P_{i+19} \ldots \cup P_i\}, \quad P_x \neq 0$$

$$R_{BH} = \{P_{i-5} \cup P_{i-4} \ldots \cup P_i \cup \cdots P_{i+4} \cup P_{i+5}\}, \quad P_x \neq 0$$

- Majority of pixels in R take the same value
- Find median intensity in R as the intensity of pixel of interest



Disparity Image Correction

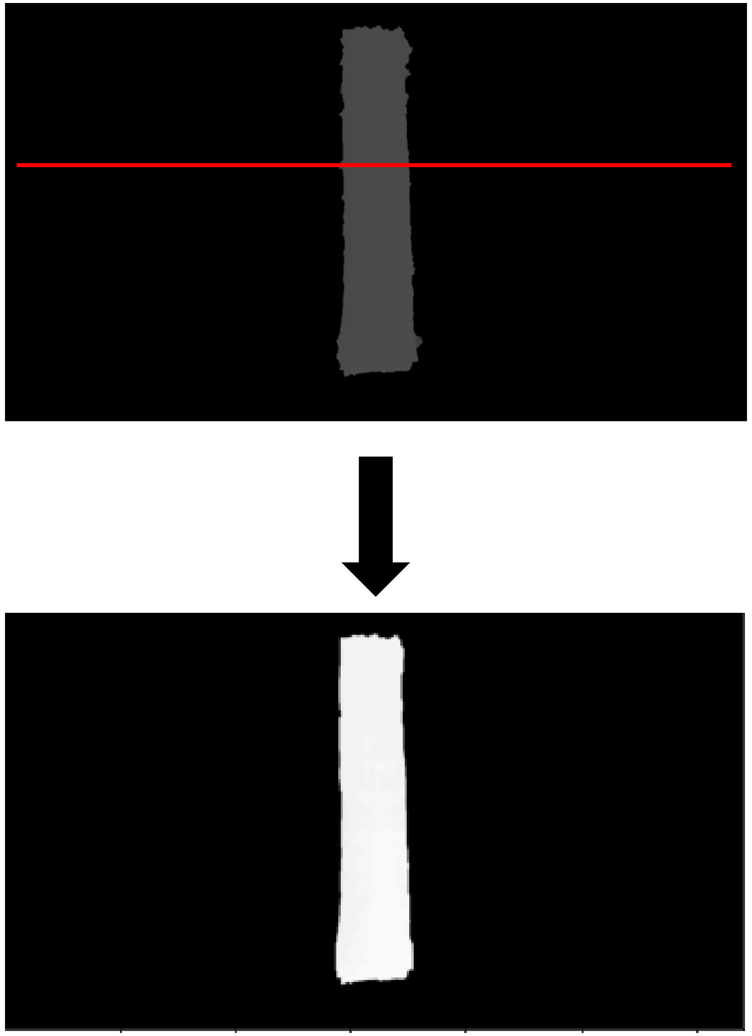
- Edges of segmented image not smooth
- Mathematical morphology
- Morphological opening (removes small white patches)

$$A \circ B = (A \ominus B) \oplus B$$

- Morphological closing (removes small black holes)

$$A \bullet B = (A \ominus B) \oplus B$$

- Used a vertical linear structuring element (20-40 pixels)



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Ground Truth Data Acquisition

CD

DBH

TH

Breast Height Estimation

Ground Truth DBH (px)	Extracted DBH (px)	AE (px)	AE (%)	AE (cm)	AE (%)
179	179	0	0.0	0.00	0.00
285	276	9	3.2	4.09	3.15
248	248	0	0.0	0.00	0.00
285	275	10	3.5	5.25	4.04
287	272	15	5.2	6.44	4.95
313	304	9	2.9	3.54	2.72
266	256	10	3.8	5.25	4.04
325	311	14	4.3	6.01	4.63
312	312	0	0.0	0.00	0.00
280	278	2	0.7	0.97	0.74

<u>10 instances</u>

MAE: 3.15 cm (2.43%)

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DBH Estimation Results @ 5m

Distance (m)	Circumference (cm)	Ground Truth DBH (cm)	Extracted DBH (cm)	AE (cm)	AE (%)
5	89.5	28.49	29.87	1.38	4.84
5	43.4	13.81	14.67	0.86	6.23
5	146.9	46.76	44.06	2.7	5.77
5	75.1	23.91	23.03	0.88	3.68
5	63.8	20.31	19.27	1.04	5.12
5	105.8	33.68	32.61	1.07	3.18
5	78	24.83	26.01	1.18	4.75
5	147	46.79	46.06	0.73	1.56
5	82.0	26.1	23.75	2.35	9.00

20 trees
MAE: 0.70 cm (1.94%)
RMSE: 0.95 cm
rRMSE: 0.09 cm
Pearson R: 0.9926

20 trees (@8m)
MAE: 0.75 cm (2.21 %)
RMSE: 1.06 cm
rRMSE: 0.1 cm cm
Pearson R: 0.9930

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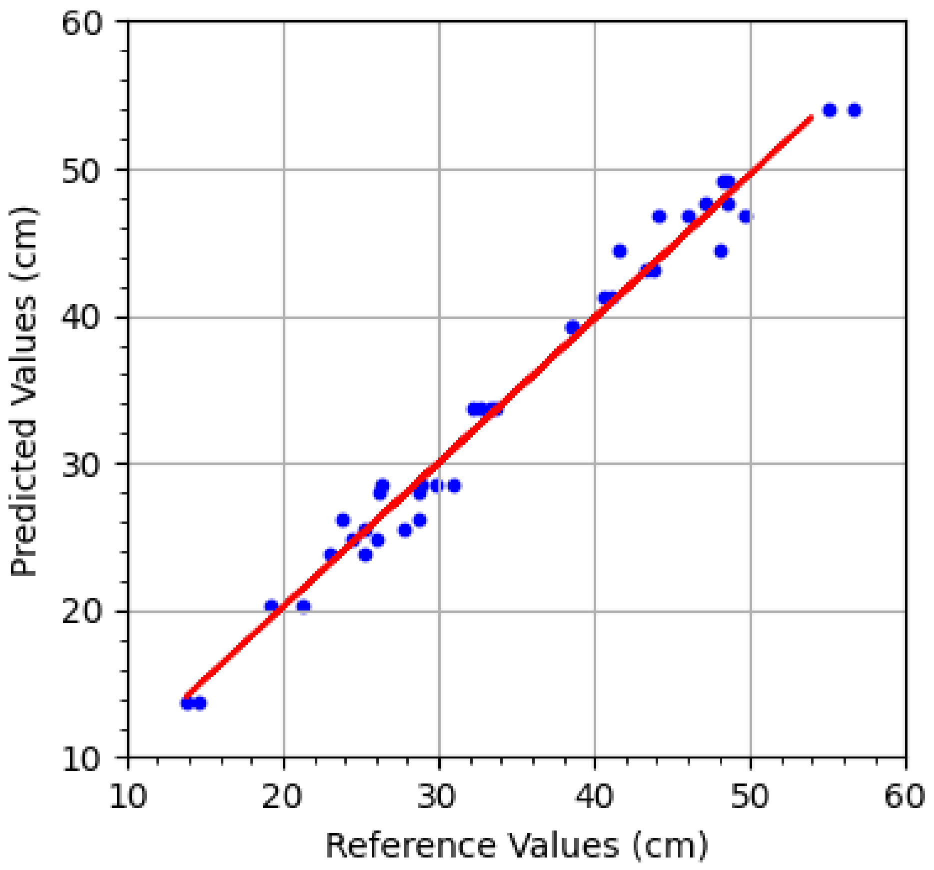
CD & TH Estimation Results

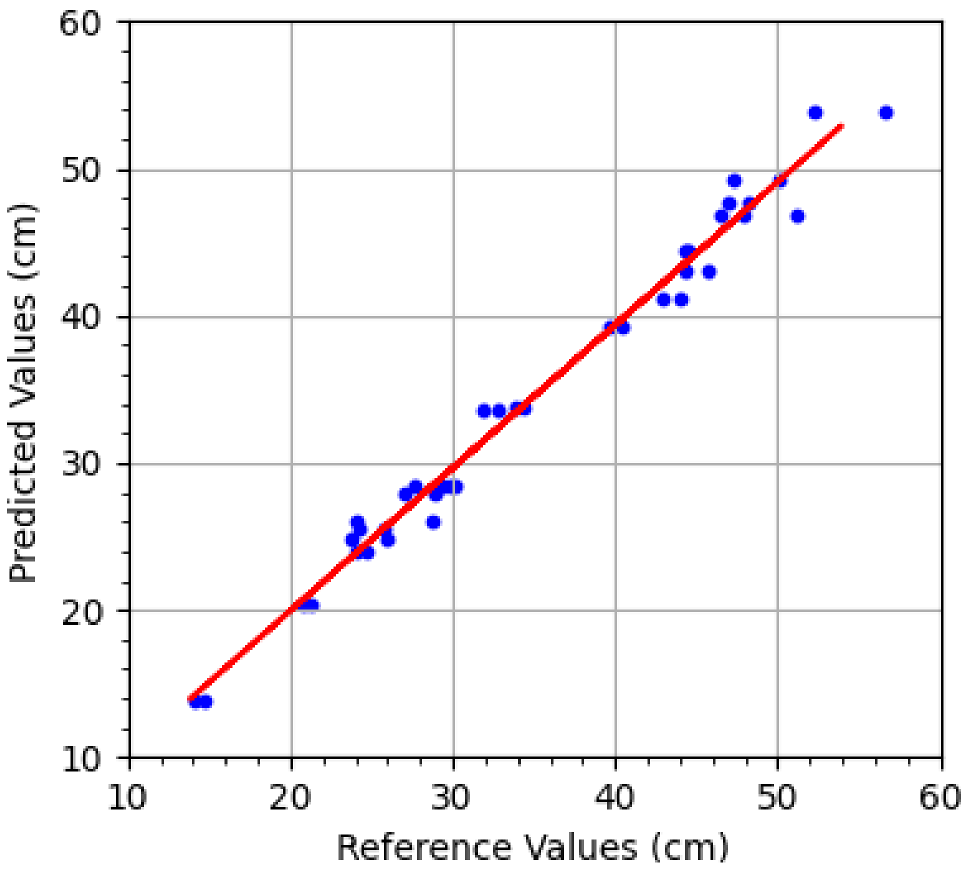
Ground Truth CD (cm)	Extracted CD (cm)	AE (cm)	AE (%)	Precision (%)	Ground Truth TH (cm)	Extracted TH (cm)	AE (cm)	AE (%)
415	353	62	14.94	85.06	339	319	20	5.90
559	525	34	6.08	93.92	453	473	20	4.42
480	514	34	7.08	92.92	567	595	28	4.94
170	174	4	2.35	97.65	251	244	7	2.79
289	282	7	2.42	97.58	281	268	13	4.63
224	230	6	2.68	97.32	362	373	11	3.04
241	214	27	11.20	88.80	359	382	23	6.41
361	402	41	11.36	88.64	398	373	25	6.28
325	333	8	2.46	97.54	491	481	10	2.04
323	373	50	15.48	84.52	395	420	25	6.33

10 trees (CD)
MAE: 27.3 cm (7.61%)
RMSE: 33.51 cm
rRMSE: 0.3cm
Pearson R: 0.9564

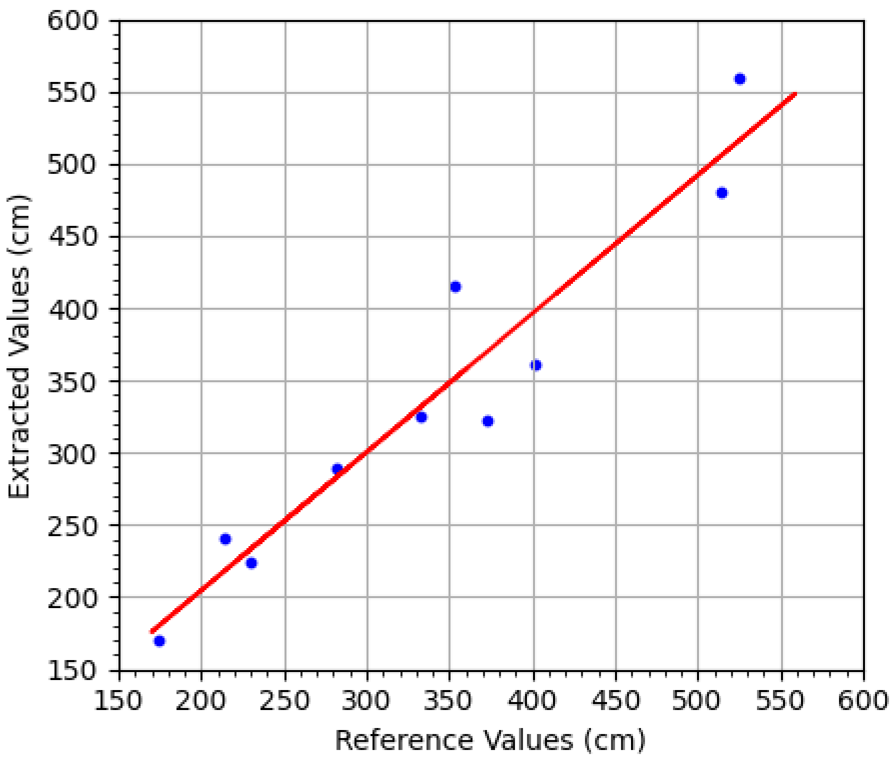
10 trees (TH)
MAE: 16.3 cm (4.19%)
RMSE: 17.92 cm
rRMSE: 0.2 cm
Pearson R: 0.9874

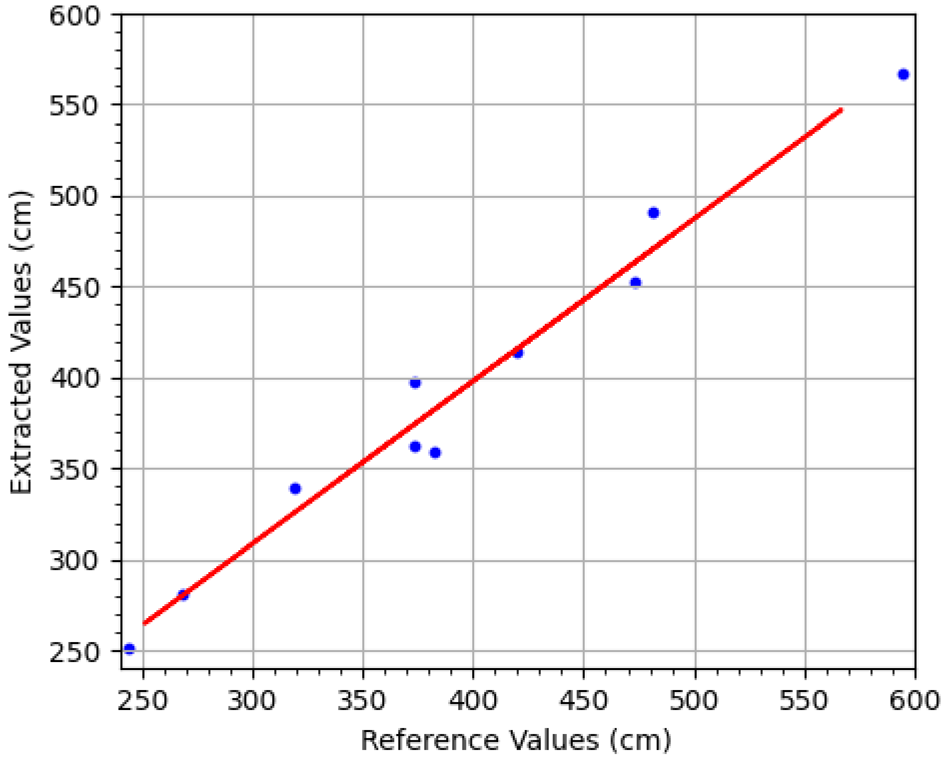
Regression Plots (DBH)





Regression Plots (CD & TH)





Limitations

- Tree trunks with bifurcation
- Slanting or curved tree trunks
- Trees taller than $\approx 6m$

Future Research

- Implement automated image segmentation using a neural network
- Addressing the challenge posed by undergrowth in forests

Thank You!

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