Automatic Tree Crown Feature Extraction from UAS Multispectral Imagery for the Detection of Bark Beetle Disturbance in an Urban Forest

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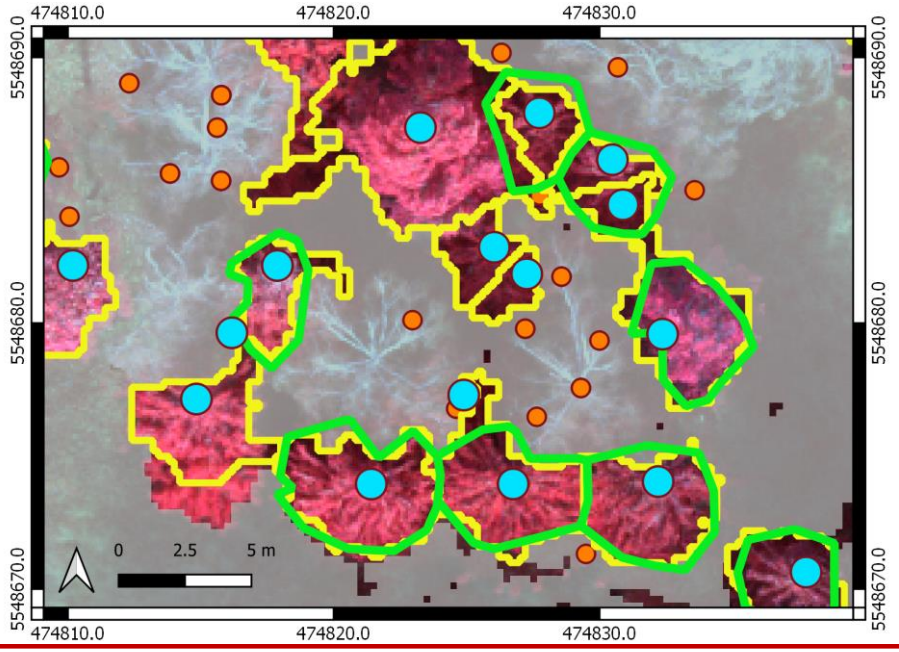
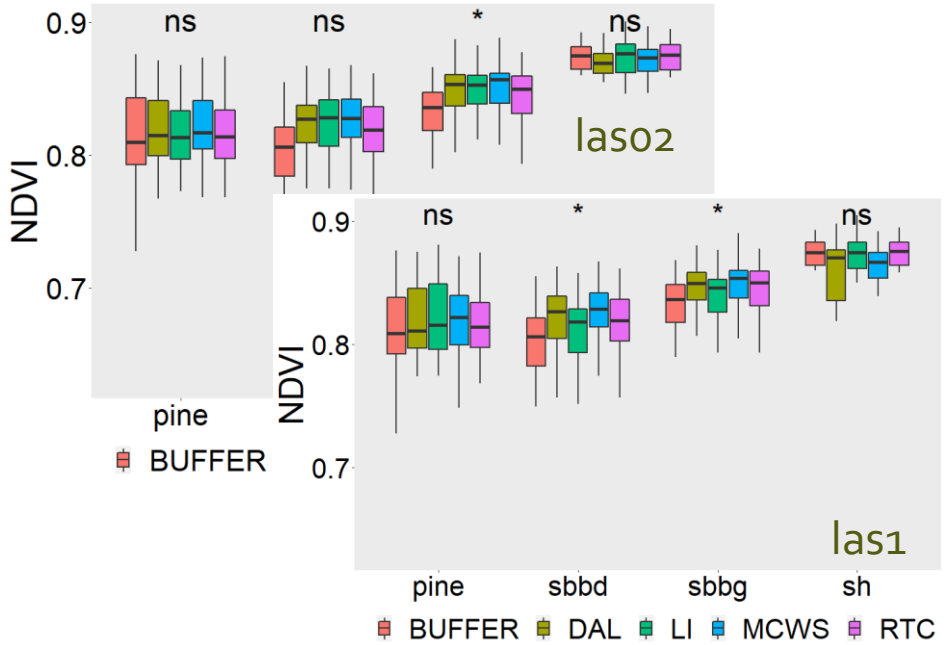
A comparison of individual tree crown delineation methods followed by feature extraction using a **masked point cloud**. Extracted **spectral and elevation features** were used to distinguish between the forest disturbance classes and two tree species.

Dataset	Point density/m2
las	701
las01	85
las02	22
las03	10
las05	4
las1	1

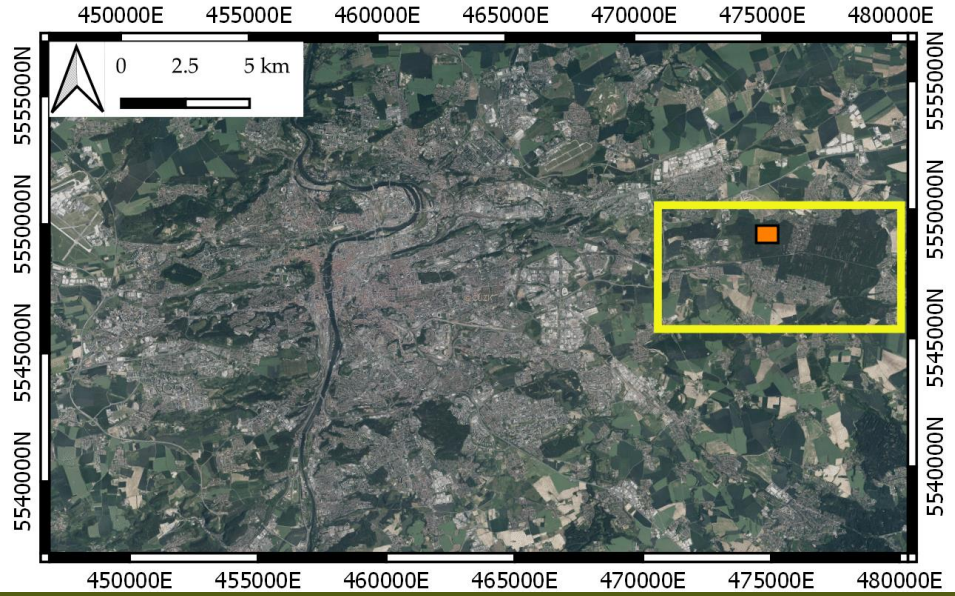




- The delineation accuracy of ITCD methods and subsequent feature extraction is affected more by PPC **density than the method used**. High-Density PPC **(>20 points/m2, 10 points/m2 min.)** is recommended.
- Buffer is not enough.

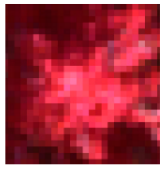
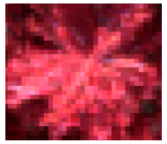
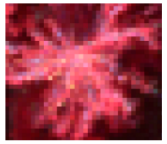
Study Area and Fieldwork

- Klánovice forest - suburban forest complex in the Prague metropolitan area.
- Spruce, Pine, Larch, Birch and Oak are dominant species.



- Study area is a mixed forest .
- 122 mature spruce trees (Picea abies) and 23 pines (Pinus sylvestris) were mapped as Ground truth data.

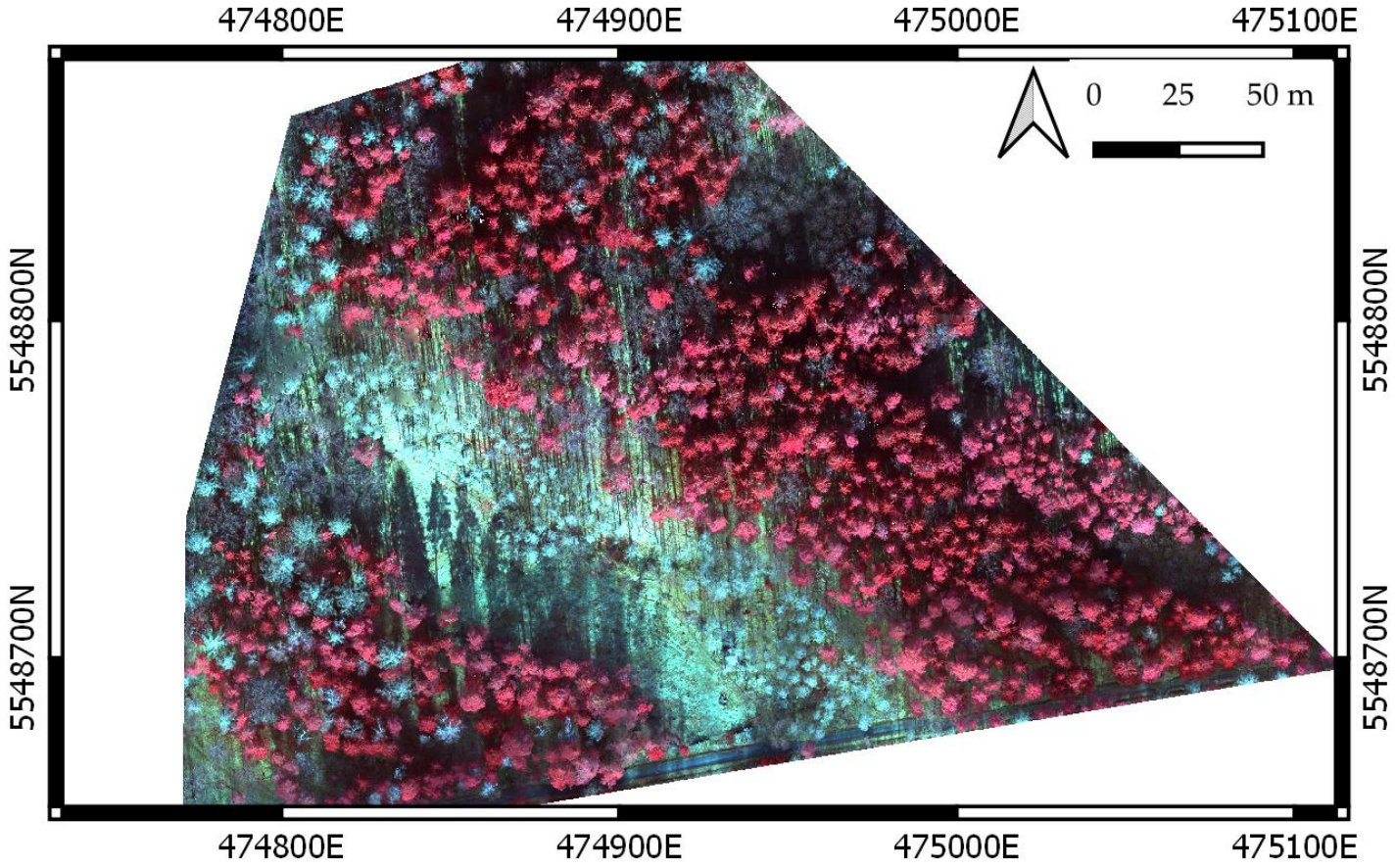
Table 3. The classification of mature spruce trees based on the field investigation. N/A indicates that resin ducts were not used to classify the tree into sbbd class.

Code	Tree Status	Canopy	Resin Ducts	N. of Trees	False Color Image *
sh	Live and not infested	needles green	absent	12	
sbbg	green attack	needles green or light green	present	69	
sbbd	damaged tree ("yellow attack")	needles light green or yellow, light green needles dropped; bark flaked away by woodpeckers	N/A	41	

* Band combination 5–3–1.

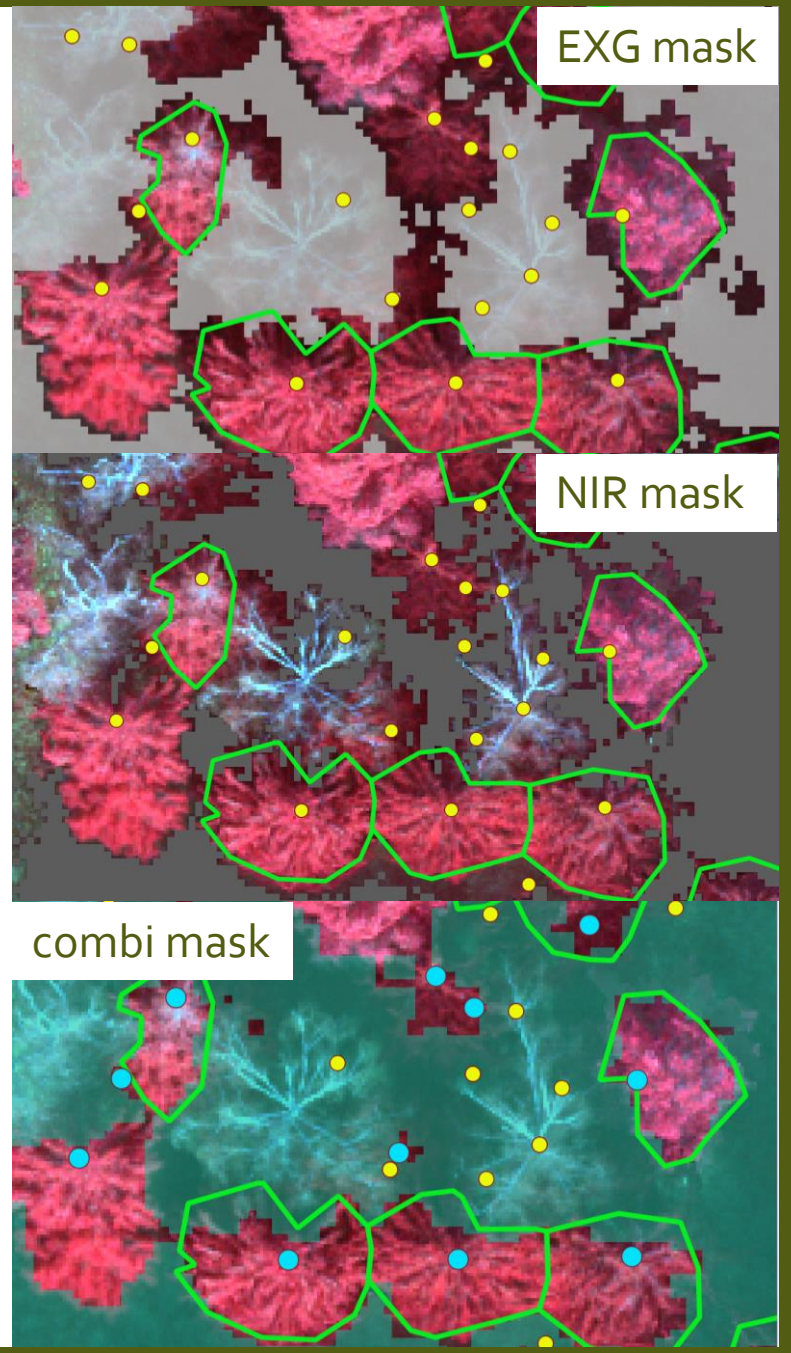
Imaging and Photogrammetric Processing

- DJI matrice 210 RTK.
- MicaSense Red-Edge.
- Agisoft Metashape – standard multispectral (MS) data processing
- MS Orthophoto 10cm/pixel and Photogrammetric point cloud (PPC) were used further.



Vegetation masks

- To separate the conifers from the background, we applied the excess green index (ExG) index threshold mask to the point cloud.
- The threshold (ExG = 0.20) for conifer trees was set according to an automatic unsupervised k-means classification of the ExG map into two classes.
- In addition to the ExG mask, we applied a near infrared (NIR) shadow mask only for the treetop's detection routine.



Tree delineation

- Tree detection routine in R using lidR package
- Inputs: Original Point cloud masked by the combi mask
- Algorithm: Local maxima filter
- Issue: Ultra-high original point cloud resulted in multiple treetops identification within one tree
- Solution: Decimation of the pointcloud, testing different densities

Dataset	Grid (m)	Point density/m2
las	N/A	701
las01	0.1	85
las02	0.2	22
las03	0.3	10
las05	0.5	4
las1	1	1

- Tree delineation routine in R using lidR package
- Inputs: decimated point clouds masked by ExG mask
- Apply Dalponte2016, LI2012, Marker-controled watershed segmentation methods and simple buffer.

Feature extraction (next slide)

Feature extraction

- In addition, to the standard geometrical accuracy assessment, the extracted spectral and elevation features from segments of DAL, MCWS, and LI were statistically compared to the extracted statistics of reference crowns.
- Performed only for the most accurate las02 and the most inaccurate las1 point clouds.
- Spectral features: NDRE, NDVI, ENDVI.
  - Issue: Similar spectral response of pines and disturbed spruces.
- These tree species have a different crown shape. So, we applied also elevation features.
- Elevation features: Crown area, zQ25 , median and zQ75 of height distribution.

Table 10. The multiple comparisons test between information (disturbance) classes within the reference dataset (RTC). True (T) or False (F) marks statistically significant/insignificant differences between pairs.

Feature	Multiple Comparisons *	Ref. Crowns
NDRE	pine-sbbd	T
	pine-sbbg	T
	pine-sh	T
	sbbd-sbbg	T
	sbbd-sh	T
	sbbg-sh	F
NDVI	pine-sbbd	F
	pine-sbbg	T
	pine-sh	T
	sbbd-sbbg	T
	sbbd-sh	T
	sbbg-sh	T
ENDVI	pine-sbbd	F
	pine-sbbg	T
	pine-sh	T
	sbbd-sbbg	T
	sbbd-sh	T
	sbbg-sh	T
crown area	pine-spruce	T
zq25	pine-spruce	T
median	pine-spruce	T
zq75	pine-spruce	T
Number of FALSE		3+0

* We used Mann–Whitney U test to test the elevation features differences of two tree species.

Results I

Table 8. The accuracy of treetop detections using a local maxima filter algorithm applied to tested PPCs with the different point density. The number of reference treetops is 145.

Dataset	Mask	Point Density (points/m^2)	Auto Treetops	TP	FP	FN	r	*p*	F-Score
lasmtopsf1	combi	701	263	137	126	8	0.94	0.52	0.67
lasmtopsf2	combi	701	226	129	126	25	0.83	0.49	0.61
las01mtopsf1 †	combi	85	142	137	5	8	0.94	0.96	0.95 *
las01mtopsf2	combi	85	121	120	1	25	0.83	0.99	0.90
las02mtopsf1 †	combi	22	143	138	5	7	0.95	0.97	0.96 *
las02mtopsf2	combi	22	123	122	1	23	0.84	0.99	0.91
las03mtopsf1 †	combi	10	148	140	8	5	0.97	0.95	0.96 *
las03mtopsf2	combi	10	124	123	1	22	0.85	0.99	0.91
las05mtopsf1 †	combi	4	156	140	16	5	0.90	0.90	0.93
las05mtopsf2	combi	4	125	124	1	21	0.86	0.99	0.92
las1mtopsf1	combi	1	200	143	57	2	0.99	0.72	0.83
las1mtopsf2 †	combi	1	133	129	4	16	0.89	0.97	0.93

* The three most accurate seed points datasets. † The seed points datasets used for further ITCD.

- Original ultra-dense point cloud (first two rows) is not usable for treetop detections.
- Sparse point cloud is less usable for treetops detection.

Results II

- It appears that the main effect of automatic tree delineation accuracy is the density of the PPC.
- A point density greater than 10 points/m2 can be considered sufficient with the margin of our results.
- If the point density is sufficient, the selection of the segmentation method is a minor issue.

Table 9. The accuracy of automatic ITCD applied to tested PPCs with the different point density.

Dataset	Mask	Method	Seed Points	OS	TP	US	FP	DA	QR	Rank
las01	ExG	MCWS	las01mtopsf1	5	119	18	1	0.82	0.40	1–3
		LI	N/A	10	117	13	4	0.81	0.42	1–3
		DAL	las01mtopsf1	9	110	19	4	0.76	0.43	1–3
las02 †	ExG	MCWS	las02mtopsf1	6	120	16	2	0.83	0.40	1–3
		LI	N/A	9	117	14	4	0.81	0.42	1–3
		DAL	las02mtopsf1	12	114	16	2	0.79	0.43	1–3
		BUFFER	las02mtopsf1	100	37	2	0	0.27	0.65	4
las03	ExG	MCWS	las03mtopsf1	5	117	18	2	0.81	0.40	1–2
		LI	N/A	11	117	11	5	0.81	0.43	1–2
		DAL	las03mtopsf1	12	111	15	4	0.77	0.44	3
las05	ExG	MCWS	las05mtopsf1	7	119	17	0	0.82	0.40	1
		LI	N/A	20	109	7	8	0.75	0.45	2–3
		DAL	las05mtopsf1	23	106	11	2	0.73	0.47	2–3
las1 *,†	ExG	MCWS	las1mtopsf2	2	100	39	3	0.69	0.47	1
		LI	N/A	67	65	3	7	0.45	0.57	2
		DAL	las1mtopsf2	57	53	15	14	0.37	0.62	3
		BUFFER	las1mtopsf02	94	34	2	4	0.23	0.65	4

OS: oversegmentation; TP: true positive; US: undersegmentation; FP: False positive; DA: detection accuracy score; QR: quality rate index. * The dataset with a significant decrease in segmentation accuracy of each applied method. † The selected datasets used for feature extraction and comparison. The BUFFER method was applied only to the selected las02 and las1 dataset for feature extraction comparison with the other automatic delineation methods.

Results III

- The significant differences among delineation methods were revealed only within sbbd and sbbg class of spectral features.
- The significant variances among delineation methods were obtained within each tree species class of all elevation features.

Table 11. The treatment versus control multiple comparison test after the Kruskal–Wallis test of spectral features. True (T) or False (F) marks statistically significant/insignificant differences between pairs. Significant differences among las02 and las1 within treatment versus control tests caused by significantly lower segmentation accuracy of las1 are highlighted in yellow.

Class	Multiple Comparisons	NDRE		NDVI		ENDVI	
		las02	las1	las02	las1	las02	las1
sbbd	RTC-DAL	F	F	F	F	F	F
	RTC-MCWS	F	F	F	F	F	F
	RTC-LI	F	F	F	F	F	F
	RTC-BUFFER	T	T	F	F	F	F
sbbg	RTC-DAL	F	F	F	F	F	F
	RTC-MCWS	F	F	F	F	F	F
	RTC-LI	F	T	F	F	F	F
	RTC-BUFFER	T	T	T	T	T	T

Table 12. The treatment versus control multiple comparison test after the Kruskal–Wallis test of elevation features. True (T) or False (F) marks statistically significant/insignificant differences between pairs. Significant differences among las02 and las1 within treatment versus control tests caused by significantly lower segmentation accuracy of las1 are highlighted in yellow.

Class	Multiple Comparisons	Crown Area		zq25		Median		zq75	
		las02	las1	las02	las1	las02	las1	las02	las1
pine	RTC-DAL	F	F	F	F	F	F	F	F
	RTC-MCWS	F	F	F	F	F	F	F	F
	RTC-LI	F	F	F	F	F	F	F	F
	RTC-BUFFER	T	T	T	T	F	F	F	F
spruce	RTC-DAL	F	T	F	F	F	F	F	F
	RTC-MCWS	T	T	F	F	F	F	F	F
	RTC-LI	F	T	F	T	F	T	F	F
	RTC-BUFFER	T	T	T	T	T	T	T	T

Conclusions

- The results revealed a strong effect of point cloud density on tree delineation and feature extraction.
- A point density greater than 10 points/m2 can be considered sufficient with the margin of our results.
- However, overly dense original photogrammetric PPC (701 points/m2) resulted in many FP treetops using local maxima filtering. Therefore, it was not usable.
- If the point density is sufficient, the selection of the segmentation method is a minor issue.
- However, the BUFFER method is less suitable for detecting a bark beetle disturbance because of the simplicity of crown delineation around a treetop.

PAPER HAS BEEN PUBLISHED.

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