Optimizing Airborne Spectral Bands for Tree Species Classification

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Introduction

- Hyperspectral data have been used in tree species classification.
- Large volume of information may result high processing cost, delay in data transmission and communication.
- Current hyperspectral sensor capture: lower spatial resolution imagery when compared with images captured using multispectral sensors.
- Weather plays the important role in defining quality of acquired images.

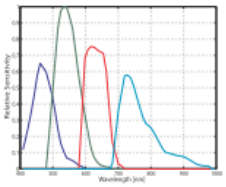
Materials

AisaEAGLE II hyperspectral sensor was used for airborne hyperspectral measurement.

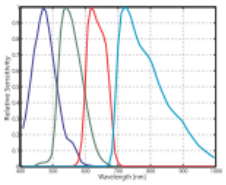
Sensor	ULTRACAM	DMC	ADS40
Scanning Principle	Frame grabbing	Frame grabbing	Pushbroom
Image Capture	Multi-head	Multi-head	Single-head
Smallest Ground Sample at	2.7 cm panchromatic at 1,000 feet above ground	3 cm panchromatic 1,000 feet above ground	5 cm panchromatic and multispectral at 1,500 feet above ground
Panchromatic Spectral Resolution	380–720 nm	400–950 nm	465–680 nm
MultiSpectral Spectral Resolution			
Blue	380–580 nm	400–580 nm	428–492 nm
Green	480–640 nm	500–650 nm	533–587 nm
Red	580–700 nm	590–675 nm	608–662 nm
Infrared	680–940 nm	675–850 nm	833–887 nm
Radiometric Resolution	12+ bit, 14 bit ADC, 16 bit storage	12 bit	12 bit (16 bit ADC storage)
Array Size	11,500 X 7,500 pixels (after pan/MS fusing)	13824 pixel X 7680 pixel (after pan/MS fusing)	12 lines x 12,000 pixels across track

Materials

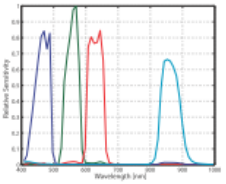
- The spectral sensitivities of the three multispectral systems.
- Sensitivities are normalized such that maximum peak value is 1.



(a) The sensitivities of the Vexcel UltraCam-D (UCD) [35].



(b) The sensitivities of the Z/I Digital Mapping camera (DMC) [36].



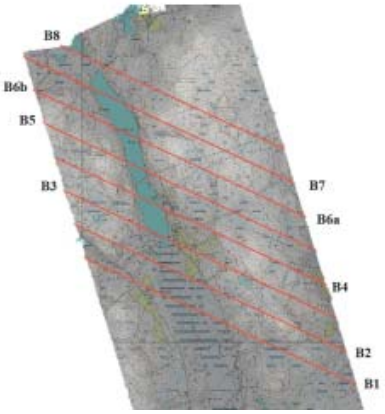
(c) The sensitivities of the Leica ADS40 [37] (ADS).

Materials

AisaEAGLE II hyperspectral bands and corresponding wavelength (WL) peak value in nanometer [nm] with a Full-Width-at-Half-Maximum (FWHM) around 9.3 nm

Band	WL	Band	WL	Band	WL	Band	WL	Band	WL
1	408.39	14	524.20	27	644.58	40	766.61	53	890.52
2	417.03	15	533.20	28	653.92	41	776.14	54	900.04
3	425.67	16	542.20	29	663.26	42	785.68	55	909.57
4	434.33	17	551.37	30	672.60	43	795.22	56	919.11
5	443.24	18	560.69	31	681.95	44	804.76	57	928.67
6	452.24	19	570.01	32	691.29	45	814.30	58	938.22
7	461.23	20	579.33	33	700.65	46	823.84	59	947.78
8	470.23	21	588.65	34	710.04	47	833.37	60	957.33
9	479.23	22	597.97	35	719.42	48	842.89	61	966.89
10	488.22	23	607.29	36	728.81	49	852.42	62	976.44
11	497.22	24	616.61	37	738.19	50	861.94	63	986.00
12	506.21	25	625.93	38	747.58	51	871.47	64	995.55
13	515.21	26	635.25	39	757.07	52	880.99		

Test Flights



Ground truth

- Altogether 577 plots (254 pine plots, 177 spruce plots and 146 birch plots) were identified from B–Line and 51 plots (21 pine plots, 20 spruce plots and 10 birch plots) were identified.
- In the plot identification process, the mean tree height was estimated for each identified plot using the LiDAR points of the stand's dominant height and stand density ($h < 2$ m).

Dataset	Height [m]		Pine	Spruce	Birch
	Min – Max	Category			
BL1	5.77–32.74	0 –10	1,706		
		10 –15	6,813	3,346	7,056
		15 – 20	24,100	7,536	17,161
		20 – 25	6,552	12,946	6,569
		25 above	860	5,994	
		Total	**40,031**	**29,822**	**30,786**
BL2	2.62–33.56	0 –10	2,188		1,323
		10 –15	11,078	803	7,056
		15 – 20	25,899	6,274	17,185
		20 – 25	1,751	11,479	6,599
		25 above		6019	882
		Total	**40,916**	**23,772**	**33,045**
DL	6.60–29.04	0 –10	535		882
		10 –15	1,685	882	881
		15 – 20	3,566	418	2,203
		20 – 25	85	3,789	441
		25 above		2,832	
		Total	**5,871**	**7,921**	**4,407**

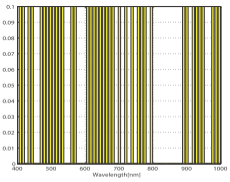
Methods –Band Selection

- Algorithms used in Band selection and selected band number
- In table the bold number represents the common bands obtained with tree algorithm.

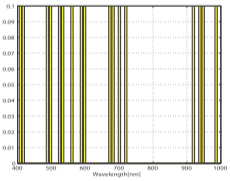
Algorithm	Name	Selected Band Positions
Sparse Linear Regression	Algo1	**1**, 2, 4, 5, 8, 9, **10**, 11, 12, 13, 14, 15, 18, 19, 23, 24, 25, 26, 27, 28, 29, **30**, 31, **33**, **35**, 37, 39, 40, 41, 43, 53, 54, 56, 57, 58, 59, 62, 63 and 64
Sparse Logistic Regression	Algo2	**1**, 2, **10**, 11, 14, 15, **19**, 21, 22, **30**, 31, **33**, **35**, 56, 58, 59, and 63
Sparse Logistic Regression with Bayesian Regularization [87]	Algo3	**1**, **10**, 19, **30**, **33**, **35**, 42 and 49

Methods –Band Selection

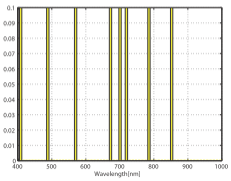
- On use of Algo3 minimum numbers of bands were selected and the algorithm has further advantage since it avoid the model selection stage.
- Using Algo3 with plot and pixel level dataset in balance cases 8–11 narrow bands were selected.



(a) Bars represented the selected spectral band positions with sparse linear regression method.



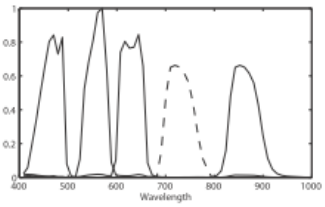
(b) Bars represented the selected spectral band positions with sparse logistic regression method.



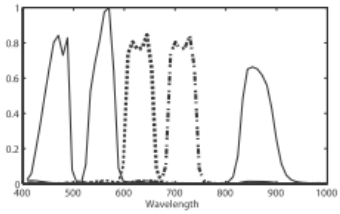
(c) Bars represented the selected spectral band positions from sparse logistic regression with bayesian regularization method [87].

Results

- The Leica ADS was chosen in band modification since it lacks sensitivities in the wavelength region of 690–800 nm
- Although, Leica ADS system lacks sensitivity in red–edge region it has been reported that certain Leica systems can have a possibility for an additional sensitivity in the wavelength region of 705–755 nm but sensitivity information was unavailable.
- First the 4th NIR band in the Leica ADS sensor was replicated and relocated to have sensitivity in the 691–785 nm region, such that there is no overlap with other existing Leica ADS



(a) The five band system *ADS** proposed in publication [*P1*].The four solid line are the Leica ADS40 sensitivity information and dashed line is the added fifth band



(b) The dotted curve is the ADS40 red band and the dashed dot curve is the repositioned band to make new multispectral system *ADS-S* and *ADS-S** proposed in publication [*P2*]

Classification results for using the selected band and simulated responses

Dataset	Features	Bands	CR (%)	Ka	Pine (CR)	Spruce (CR)	Birch (CR)	Difference from AISAE accuracy (%)	95% CI	Conclusion (at 0.05 level of signifi-cance)
BL1	**AISAE**	**64**	**94.29**	**0.922**	**92.62**	**94.28**	**98.38**	**0.0**	**(0.0 – 0.0)**	**No change**
	Algo1	39	94.63	0.922	92.56	94.00	98.73	-0.339	– –	–
	Algo2	17	93.86	0.912	91.99	92.43	98.72	0.432	(0.430 – 0.432)	Non-Inferior
	Algo3	8	93.73	0.909	92.46	92.08	97.88	0.590	(0.588 – 0.590)	Non-Inferior
BL2	**AISAE**	**64**	**94.30**	**0.916**	**92.91**	**93.48**	**97.10**	**0.0**	**(0.0 – 0.0)**	**No change**
	Algo1	39	93.88	0.908	92.00	92.86	97.21	0.420	(0.418 – 0.420)	Non-Inferior
	Algo2	17	94.06	0.911	91.91	93.05	97.72	0.236	(0.234 – 0.236)	Non-Inferior
	Algo3	8	93.84	0.909	92.97	92.69	96.42	0.455	(0.453 – 0.455)	Non-Inferior
DL	**AISAE**	**64**	**90.31**	**0.857**	**92.06**	**84.55**	**99.88**	**0.0**	**(0.0 – 0.0)**	**No change**
	Algo1	39	90.13	0.860	94.00	83.67	99.77	0.181	(0.174 – 0.187)	Non-Inferior
	Algo2	17	89.35	0.849	93.06	82.75	99.63	0.965	(0.958 – 0.971)	Non-Inferior
	Algo3	8	89.38	0.843	92.47	82.52	98.97	0.931	(0.925 – 0.937)	Non-Inferior

Height-based tree species classification results for datasets

Dataset	Feature	Height [M]	CR (%)	κ	Pine (CR)	Spruce (CR)	Birch (CR)
BL1	AISAE	10 –15	96.06(0.74)	0.94(0.01)	94.49(1.02)	92.86(2.91)	99.85(0.07)
		15 – 20	93.19(1.04)	0.89(0.02)	90.30(1.95)	91.82(2.54)	98.60(0.56)
		20 – 25	89.97(1.26)	0.85(0.02)	89.83(1.44)	88.42(2.19)	94.88(2.00)
	SparLog	10 –15	96.30(0.62)	0.95(0.01)	94.93(1.17)	92.91(2.18)	99.82(0.10)
		15 – 20	93.37(0.69)	0.90(0.01)	90.32(1.46)	92.33(1.92)	98.50(0.49)
		20 – 25	89.96(1.04)	0.85(0.02)	89.75(2.58)	88.19(1.89)	94.81(1.69)
BL2	AISAE	10 –15	95.83(0.30)	0.93(0.01)	96.20(0.74)	88.08(5.45)	96.81(0.78)
		15 – 20	92.60(0.80)	0.88(0.01)	89.24(1.66)	92.90(1.36)	98.65(0.44)
		20 – 25	89.15(1.14)	0.82(0.02)	86.58(3.70)	87.63(2.26)	94.20(1.88)
	SparLog	10 –15	95.40(0.99)	0.92(0.02)	95.67(1.59)	85.75(4.23)	96.48(0.80)
		15 – 20	92.12(1.11)	0.87(0.02)	88.54(2.29)	92.34(1.63)	98.04(1.23)
		20 – 25	88.65(1.32)	0.81(0.02)	86.43(3.69)	87.14(2.14)	92.62(2.46)
DL	AISAE	10 –15	94.39(1.56)	0.92(0.02)	94.18(2.19)	92.36(3.60)	97.86(1.98)
		15 – 20	95.32(1.02)	0.92(0.02)	94.69(1.76)	86.09(5.77)	98.34(0.80)
		20 – 25	88.34(1.20)	0.63(0.03)	71.45(14.60)	88.09(1.42)	98.05(2.16)
	SparLog	10 –15	94.07(1.68)	0.91(0.02)	93.95(2.27)	94.28(3.26)	95.50(3.71)
		15 – 20	94.36(1.04)	0.90(0.02)	93.34(1.59)	82.55(7.62)	98.59(0.65)
		20 – 25	88.45(2.78)	0.64(0.06)	76.51(19.84)	88.39(2.82)	97.59(3.85)

The classification results obtained from evaluating the effect of view-illumination geometry.

Dataset	Features	CR (%)	κ	Pine (CR)	Spruce (CR)	Birch (CR)
Tr (BL1) / Te (BL2)	AISAE	92.9 (0.4)	0.90 (0.01)	88.9 (1.8)	93.6 (1.5)	98.1 (0.3)
	SparLog	92.0 (0.4)	0.88 (0.01)	88.2 (1.6)	92.3 (1.4)	97.3 (0.3)
Tr (BL2) /Te (BL1)	AISAE	92.8 (0.4)	0.89 (0.01)	93.3 (1.1)	86.2 (1.4)	97.8 (0.4)
	SparLog	92.1 (0.3)	0.88 (0.3)	92.3 (0.7)	84.5 (1.2)	98.0 (0.4)
Tr(DL) / Te (BL1)	AISAE	74.8 (4.2)	0.63 (0.06)	65.1 (16.8)	82.9 (10.7)	81.8 (4.3)
	SparLog	77.1 (2.3)	0.66 (0.03)	70.2 (6.3)	82.8 (4.2)	82.1 (3.8)
Tr(DL) / Te (BL2)	AISAE	72.7 (5.6)	0.61 (0.08)	61.1 (16.8)	83.9 (10.0)	80.9 (4.0)
	SparLog	76.7(2.0)	0.66 (0.03)	69.4 (4.9)	79.8 (4.7)	84.6 (3.0)
Tr (BL1) / Te (DL)	AISAE	78.7 (5.3)	0.70 (0.08)	82.4 (14.9)	73.8 (7.7)	90.0 (3.4)
	SparLog	76.0 (5.2)	0.65 (0.08)	66.5 (14.9)	77.6 (4.2)	89.8 (2.3)
Tr (BL2) / Te (DL)	AISAE	80.2 (3.2)	0.72 (0.05)	77.6 (13.5)	80.5 (11.1)	90.1 (5.7)
	SparLog	80.7 (2.6)	0.72 (0.04)	78.2 (9.1)	79.7 (4.8)	89.4 (1.9)

Discussion

- A decrease in tree species classification accuracy was observed as the tree heights increased, even though the training and test datasets are characterized by the same view-illumination geometry.
- The result can be explained by data properties in training and test set.
- It can be assumed that for taller trees additional ground information or proper selection of field plots is needed to develop a training set which could provides improved the classification accuracy.
- Moreover, tree species classification experiment showed that eight selected bands preserves the tree species classification (approximately 1–2% point) as obtained on using all 64 AisaEAGLE II hyperspectral bands through view-illumination geometry and in tree height.

Discussion

- The tree species classification results obtained on using the selected bands and the simulated responses of proposed 4 and 5–band sensor sensitivities showed that in future tuning an imaging band position in pre-flight setup or developing multispectral sensor system with the small number of optimized bands allowed us to extract adequate information of an object on the ground.
- With this information similar tree species classification performance could be obtained as obtained on using all the hyperspectral bands.

Discussion

- When we used the mixed view-illumination geometry dataset DL for training and the fixed view-illumination geometry dataset (BL1 or BL2) as the test set or vice versa, we obtained a classification accuracy of 74–80%.
- This is approximately a 12–18% point decrease in the accuracy when compared with the other results. Furthermore, there was also a drop in the accuracy of the classification of the individual tree species.
- The largest drop was observed in pine (a maximum of 32% point), where spruce and birch accuracy decreases approximately 17–20% point