CANAPI: Canopy Analysis with Panchromatic Imagery for Validation of Moderate Resolution Canopy Structure Products

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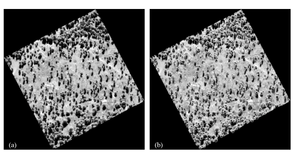
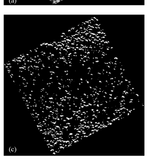
Objective: The validation of remotely-sensed canopy structural parameters derived from moderate resolution imaging is a perennial problem because it is too expensive to undertake field measurements at scales of 250 m and above. High resolution imaging from the air and space and airborne lidar systems are widely used sources of reference data, with the former used to delineate crowns and the latter to estimate crown heights and other statistics. A simple yet effective method that provides tree crown extent, radii, and heights maps from high resolution panchromatic images of large dimensions – CANAPI (CANopy Analysis from Panchromatic Imagery) – is presented here, together with comparisons with QuickBird 0.6 m spatial resolution imagery, EVI field lidar, and lidar height estimates from the NASA Laser Vegetation Imaging Sensor (LVIS) for forest sites in the Sierra Nevada mountain range in California. The method was developed as an ImageJ macro using simple image processing functions and is easily modified and extended, for example to obtain estimates of crown shape. CANAPI has some limitations - e.g., it is not adapted for closed and/or tropical forest canopies - but is useful in obtaining cover and height estimates for extensive areas in open and semi-open forest and shrub canopies where illumination is oblique. The results can also be used to establish background reflectance magnitude and anisotropy metrics predicted using multiangle bidirectional reflectance factors or a bidirectional reflectance distribution function (BRDF) model.





(d) Results Table

	Area	BX	BY	Width	Height	radius	shadowlen	theight
1277	20	260	747	7	6	3.50	2.10	5.20
1278	29	300	747	8	6	4	-1	-1
1279	42	364	747	8	8	4	3	7.43
1280	14	318	750	5	5	2.50	1.50	3.71
1281	20	252	751	5	7	2.50	1.50	3.71
1282	124	265	751	21	10	10.50	-1	-1
1283	34	327	752	7	7	3.50	5.70	14.11
1284	10	317	758	4	4	2	1.80	4.46
1285	91	347	759	21	7	10.50	0	0
1286	12	370	760	5	3	2.50	0	0
1287	40	290	761	8	7	4	8.40	20.79
1288	24	340	763	7	6	3.50	2.10	5.20
1289	35	258	764	7	8	3.50	2.10	5.20
1290	49	284	765	8	9	4	-1	-1
1291	44	298	765	9	7	4.50	-1	-1
1292	54	313	765	12	9	6	0	0
1293	12	334	772	6	4	3	1.80	4.46
1294	49	265	776	10	7	5	-1	-1
1295	79	301	777	17	8	8.50	0	0
1296	46	326	777	11	7	5.50	0	0
1297	92	279	781	23	7	11.50	8.10	20.05
1298	34	271	788	9	5	4.50	2.70	6.68
1299	64	287	797	16	7	8	0	0

Fig. 1. CANAPI operation (a) stretched 0.6 m QuickBird panchromatic image, rotated so that the solar direction is at the top of the image (b) the same image with the crowns and shadows delineated. Shadows are not drawn if they are deemed to fall on an adjacent crown. (c) the illuminated crown map (d) example results table. BX, BY, Width and Height refer to the bounding rectangle fitted to the illuminated crown objects by ImageJ's Particle Analyzer; shadowlen and theight are shadow lengths and estimated tree heights, respectively, in meters.

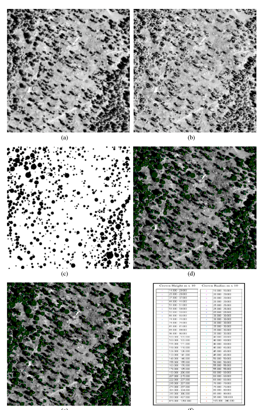
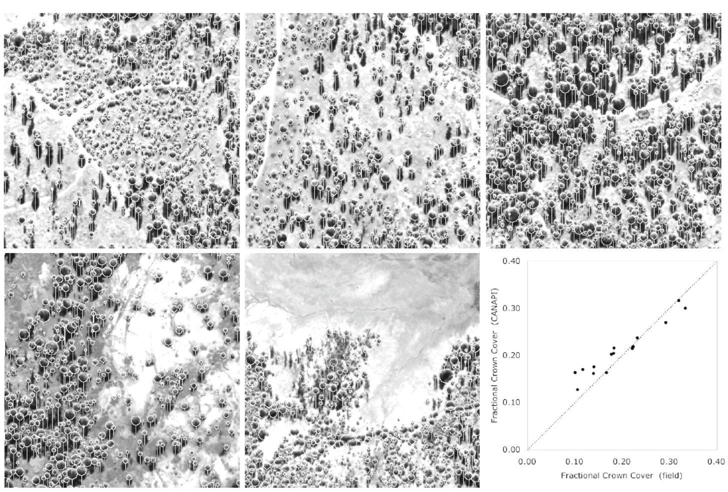


Fig. 2. Visualization of results (a) stretched QuickBird 0.6 m panchromatic image (b) with crown radii and valid shadows delineated (c) vectorized output crown map (d) with tree heights at crown centres (e) with tree radii at crown centres (f) legends for (d) and (e).



Algorithm: The algorithm leverages the power and flexibility of the open-source Java-based ImageJ package developed at the United States National Institutes for Health (Rasband, 1997). It first identifies crowns by finding the approximately crescent-shaped areas that correspond to illuminated crown, for image windows with typical dimensions of 2000 x 2000 pixels. This is achieved by rotating the original image so that the sun direction is at the top of the image (figure 1 (a) and (b)). A stretch is then applied to enhance contrast and a convolution operation performed to emphasize sunlit crown, followed by 3 x 3 median filtering to reduce noise and thresholding to isolate the sunlit crowns in a binary image (figure 1 (c)). A watershed operation is performed in an attempt to separate contiguous adjacent sunlit crowns and ImageJ's Particle Analyzer is run to create a results table that holds the area, location and dimensions of the smallest rectangle that encloses each object (figure 1 (d)). For each object, the location of the centre pixel is determined using the rectangle location and dimensions and the radius of each crown is calculated and added to the table. A binary crown raster map is updated with all crowns detected and radii values x 10 are written into crown centre pixels in a 16-bit crown radii raster map.

The second part of the algorithm attempts to estimate tree heights by delineating crown shadows. The original image is duplicated, converted to 8-bit, stretched, and one is subtracted from all pixel values to remove any with a value of 255; a circle representing each crown that meets user-defined size criteria is then drawn on this image using this value (figure 1 (b)). For each object, the algorithm evaluates pixel values in a vector that grows from the crown edges in the shadow direction (i.e., towards the bottom of the image), stopping when a user-defined threshold is encountered and flagging vectors that end in an adjacent crown rather than the ground, extend to the edge of the image, or are unfeasibly long. Tree height is calculated using knowledge of the solar elevation angle. The results table is updated with the estimated tree height in meters (figure 1 (d)) and valid height values x 10 are written into crown centre pixels in a 16-bit crown heights raster map.

Fig. 3, Right: Tree crowns delineated by CANAPI (centers = dots; original crown data are circles), field measured crown (red circles), and horizontal-projected crown area from EVI ground lidar point cloud (gray area) for site 305. The largest source of error in CANAPI estimates is from the merging of multiple crowns, resulting over-estimation of crown area; however few crowns are missed. We are repeating this assessment of CANAPI results for many other sites in the study area.

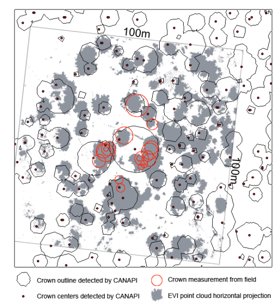


Fig. 4, Right: (a) LVIS RH100 canopy heights interpolated onto a 20 m grid: black to white = 0–70 m (b) CANAPI tree heights as points at crown centres: red=high, purple=low, white=0 (c) scatter plot for a subset of the area using LVIS RH100 interpolated to 60 x 60 m grid and excluding cells with < 9 trees or < 3 m in minimum height in the CANAPI/QB estimates.

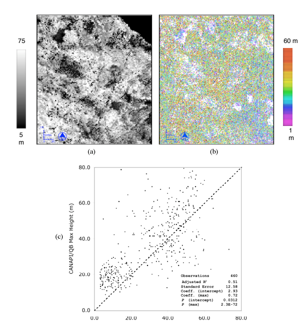


Fig. 5, Left: Typical CANAPI operation, showing delineated crowns (circles) and lines tracing tree shadows. Note that spurious detections are very rare. The scatter plot shows the relationship between field-measured crown cover from the Teakettle Ecosystem Experiment database and CANAPI crown cover is very good, with an adjusted R^2 of 0.92 and $p<0.01$. Each data point represents one of the fifteen 200 x 200 m Teakettle Ecosystem Experiment plots.

Conclusions: In many environments the inversion of canopy reflectance models for retrieval of canopy parameters such as fractional cover and mean canopy height depends heavily on the quality of predictions of the background contribution. It has been shown that background reflectance magnitude and anisotropy can be obtained via MISR red band kernel weights of suitable crown cover data are available. CANAPI is thus one method for obtaining cover values at the scales required for calibration of the background, as well as for validating model inversion results. The method could also be extended to provide estimates of crown aspect ratio that are important in geometric-optical models.

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