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Technical Note: Use of digital surface model for hardwood rangeland monitoring

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Abstract

We built digital surface models (DSM) that contain 3D surface morphological information of the entire landscape using digital photogrammetry and aerial photographs. Changes in landscape components such as crown closure and tree height in hardwood rangeland were estimated using DSM. In comparison with manual interpretation results, errors of crown closure and tree hieght estimation using DSM were less than 0.7% and 1.5 m, respectively. This technique can be used for rangeland management, monitoring and ecological studies.

Key Words: Digital photogrammetry, photo-ecometrics, tree heights, crown closure

Resumen

Mediante el uso de fotogrametráa digital y fotografáas aéreas construimos modelos de superficie digital (DSM) que contienen información en tercera dimensión (3D) de la superficie morfológica del paisaje completo. Con el uso de DSM se estimaron los cambios de los componentes del paisaje tales como lo cerrado de la copa y la altura de los áboles de un pastizal con áboles de madera dura. En comparación con los resultados de interpretación manual, los errores de estimación de lo cerrado de la copa y altura de los áboles con el uso de DMS fueron menos del 0.7% y 1.5 m respectivamente. Esta técnica puede ser utilizada para el manejo y monitoreo de pastizales y estudios ecológicos.

Hardwood rangelands cover 10% of California, and are composed of an overstory of various hardwood species, predominantly in the genus *Quercus,* and an understory mainly of introduced annuals (Griffin 1978, Bartolome 1987). Tree crown closure, also referred to as crown cover, canopy cover, and canopy closure, is defined as the percent of forest area occupied by the vertical projection of tree crowns (Avery and Burkhart 1994). It is commonly used as a measure of stand density and often used as an important indicator of wildlife habitat. Air-photo interpretation techniques have been used on these areas for hardwood classification and tree crown closure estimation. However, they are dependent on the experience of photo interpreters. Some experiments indicate that there are large discrepancies among photo interpretation results carried out by different interpreters (Biging et al. 1991, Gong and Chen 1992, Davis et al. 1995). It is difficult to develop detailed vegetation maps at the individual tree level with existing satellite imagery such as IRS, SPOT HRV and Landsat TM data because of their low spatial resolution ranging from 6 to 30 m (Congalton et al. 1991, Brockhaus and Khorram 1992, Franklin 1994). Even with high-resolution (0.5 to 2 m) multispectral videography, it is difficult to derive crown closures of conifer forest using traditional image analysis methods such as image thresholding and classification (Biging et al. 1995).

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Aerial photography with conventional aerial cameras and digital cameras has some advantages over other remote sensing alternatives. First, it acquires images through a central perspective making the image geometry easier to model and hence it has better geometric precision. Secondly, it has the best spatial resolution in remote sensing, usually better than 0.1 m. Beside the wider radiometric range and high spectral resolution, the spatial resolution of digital cameras is improving rapidly. We were able to acquire aerial digital images with better than 0.2 m resolution using commercially available digital cameras. In this paper, we report some of the preliminary results obtained from applying digital photogrammetry to aerial photographs for the purpose of hardwood rangeland monitoring.

Digital Photogrammetry

Digital photogrammetry is a computerized technique that automates the measurement and mapping process of traditional photogrammetry (Saleh and Scarpace 1994). A major challenge in digital photogrammetry is image matching, a critical procedure that finds image points corresponding to the same ground point from a stereopair. Although many image matching algorithms have been developed (Ackermann 1996), this process is error-prone in forest and urban areas where abrupt vertical changes are common. We are currently working in this area to improve image matching accuracy.

The 2 primary uses of digital photogrammetry are digital elevation model (DEM) development and orthophoto generation. A

DEM of an area is usually an array of grid points of ground elevation that excludes the heights of landscape features such as trees and buildings. A digital surface model (DSM), which is an array of grid points of elevation including landscape features, is necessary for deriving tree measurements in woodland and forest settings. An orthophoto is a photo of an area with a constant scale, and free from point displacement caused by elevation differences and lens distortion. Therefore, area measurements from orthophotos are more accurate than from raw aerial photographs (Gong et al. 1999).

Figure 1 shows the results from digital photogrammetry when applied to 2 sets of scanned aerial photographs acquired in July 1970 and August 1995. The original photos were acquired with a nominal scale of 1:12,000 at the upper Gallinas Valley (38°02'38" N, 122° 36'30"W), Marin County, California. They were scanned at approximately 25m µm from black and white diapositives on a Vexel 3000 scanner. The digital photogrammetric software used to analyze these photos was VirtuoZo®, a commercial software package from VirtuoZo Inc., Australia. Results shown here were generated automatically from VirtuoZo that employs the following procedures of digital photogrammetry:

(1) internal orientation. Establishes the coordinate system for each photograph based on camera frame size, position of principal point, focal length of the camera lens and the image scanning parameters.
(2) relative orientation. Determines the spatial position of the exposure stations and camera attitude parameters for both the left and right photos of a stereopair. This has been achieved in this study using 8 ground control points found in the photos by precisely measuring their ground coordinates at the centimeter level in the field with differential GPS equipment.
(3) epipolar image resampling. Resamples the left and right images according to the flight line direction so that conjugate image points can be searched along a line parallel to the flight line. Thus the image matching is simplified from a 2D matching to 1D matching.
(4) image matching. Automatically searches the conjugate image points from the left and right photos according to a similarity criterion. The absolute parallax for each image point can then be calculated. It enables the derivation of elevation for that image point. Matching algorithms are proprietary to software vendors. The precision of most matching algorithms is within one pixel. Some can reach the subpixel level. Assuming a single-pixel matching precision, the vertical resolution of the elevation data obtained here is approximately 0.5 m.

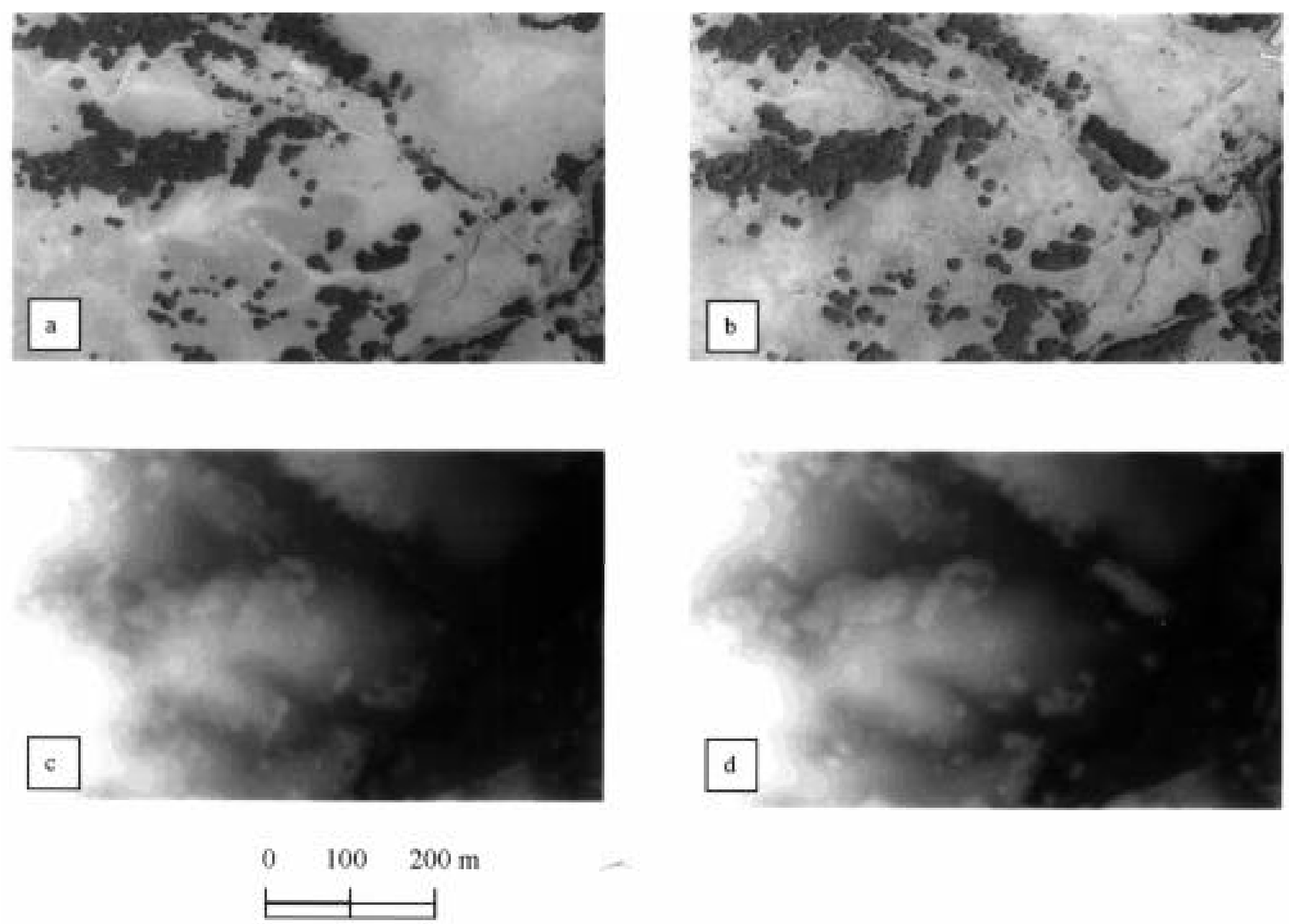

Fig. 1. Orthophotos and digital surface models (DSM) of a hardwood rangeland area in California. a. the orthophoto derived from the 1970 aerial photography, b. the orthophoto from 1995 aerial photography, c. DSM for 1970, and d. DSM for 1995. Gray scales in c and d represent surface elevation as derived from digital photogrammetry. Those mushroom-shaped bright patches in c and d are oak canopies.

(5) absolute orientation. Determines the mathematical transformation between the image coordinate system to a geodetic coordinate system or a map coordinate system such as the Universal Transverse Mercator (UTM) system.
(6) DSM generation. Calculates the elevation for a selected subsample of image points in a stereopair using the absolute parallax determined earlier. Due to computational complexities and difficulties in correctly matching every image point, most commercial algorithms match only a sample set of the total image points. The elevations for the rest of the image points in the image area are usually interpolated from those sample points. This smoothes elevation differences when sharp changes in elevation are encountered, causing deformation of objects with relatively steep slopes such as buildings and trees. This is a shortcoming of the existing image matching algorithms.
(7) DEM generation. To generate a DEM, some additional algorithms are employed. These include the detection of landscape features such as buildings and trees and the removal of their heights from the DSM. Then spatial interpolation can be used to estimate the ground elevation at the locations where objects such as trees or buildings occur.
(8) Orthophoto or contour map generation. Once the DEM or DSM is available, it can be used to rectify the perspective projection of the original raw imagery to an orthophoto with an orthographic projection. In theory, the DEM can not completely remove the image point displacement caused by object height. Such displacements can only be completely removed by an accurate DSM as it captures the elevations from both the terrain and landscape features on top of it. A contour map can be generated from either the DEM or DSM.

Hardwood Change Monitoring

Figures 1a and 1b show orthophotos for the same area from 1970 and 1995, respectively, which were generated by correcting for the scale variation in the original photographs using the 1970 and 1995 DSMs, respectively. The scanned image resolution was approximately 0.3

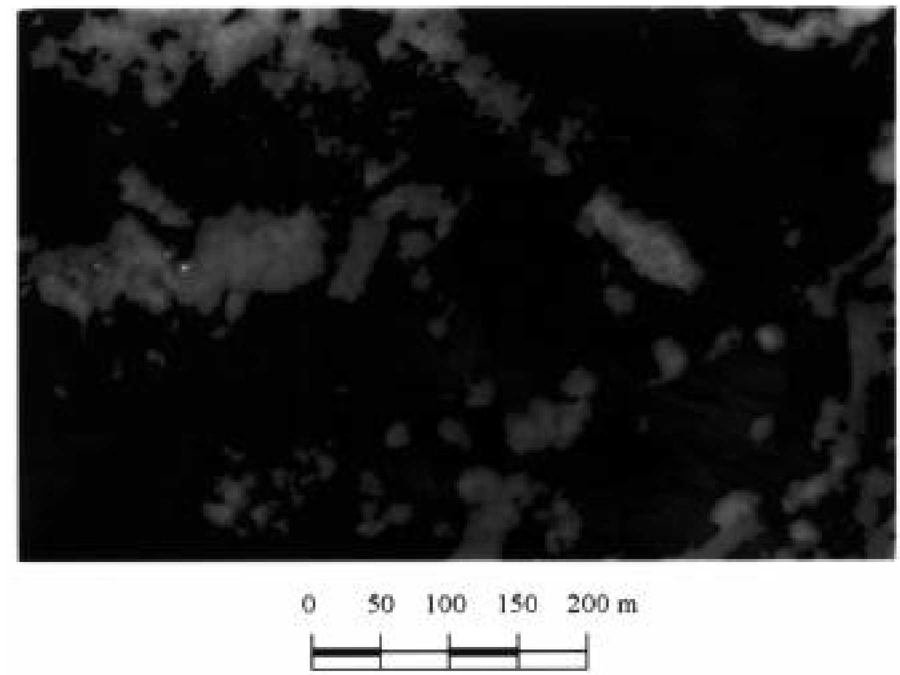

Fig. 2. The 1995 canopy morphological (height) model. This was obtained by deriving a digital elevation model (DEM) from the 1970 aerial photography then taking the difference between the 1995 DSM and the DEM. The terrain background is in black and the brightness corresponding to the height oak canopies.

m. The grid spacing used to extract the DSMs was approximately 1 m. The DSM shown in Figs 1c and 1d were interpolated to 0.3 m horizontally. The surface cover is mainly hardwood rangeland. Clusters of relatively bright areas, in Figs 1c and 1d, are coast live oaks (*Quercus agrifolia* Née). Coast live oaks can be extracted from Figs 1a and 1b through a simple image thresholding as they are radiometrically darker than their surroundings (dry grass). Changes of crown closure can be obtained by comparing the 2 thresholded images. However, this radiometric thresholding technique suffers from shadow and shading caused by the hilly topography. It is likely to produce crown closure estimates that are exaggerated. Although the shading and shadowing effects may be reduced by stratifying the study area according to the lighting conditions and by applying thresholding to each stratification, this will considerably increase the amount of work through manually partitioning the image area and editing the thresholding results. A new alternative to crown closure measurement is to threshold the heights from a crown height image derived from the DSM. This new height thresholding approach is not affected by the variation in lighting conditions but dependent on the accuracy in height determination, particularly at the edges of tree crowns whose slopes are sharp.

To evaluate the accuracy of the 2 crown closure measurement methods, we carefully digitized the oak woodland cover from a portion of the 1995 orthophoto by excluding shadows. The crown closure percentage was 26.6% (8,1962 m^2 tree cover divided by the total area of 30,7932 m^2). The crown closure results obtained from radiometric thresholding were treated as the reference data for comparison with crown closure obtained from height thresholding. The best crown closure estimated with the radiometric thresholding method was 31.0% (95486 m^2 tree cover), which yielded a 4.4% overestimate of crown closure in comparison to the reference value. This overestimation was primarily caused by the difficulty in separating shadow and shade areas on the orthophoto from the tree canopies.

On the 1970 DSM, the tree crown portion can be processed by first excluding the tree crowns. After excluding the tree crowns, we can use interpolation to estimate the ground surface elevation in the areas occupied by tree crowns. Although the interpolation can be done in commercial GIS software packages such as terrain analysis modules in the ESRI Arc/Info, we did it by manual editing on the computer screen. This process gives us a DEM. Assuming that the topography does not change in this area, we subtracted the DEM from the 1995 DSM to produce a crown height image (Fig. 2). Tree heights and crown closure can be measured from this image. Experimenting with a few height thresholds, we obtained the best results with a threshold of 2 m. The crown closure estimate was 27.3% (84,173 m^2 tree cover), only 0.7% overestimate of crown closure in comparison to the reference data. We applied this methodology to both the 1970 and 1995 crown height images to determine the changes in crown closure. There was an overall net change of approximately +1.4% in crown closure over our study area during this 25-year period. However, this number is comprised of 3 components—increase in canopy closure due to growth in existing tree crown dimensions, increase due to recruitment of new trees (regeneration) and decrease due to tree mortality. There was approximately a 5.0% decline (relative to 1970) in crown closure due to tree mortality. The surviving trees accounting for a growth in crown closure of approximately 6.4%.

The brightest spots on each tree crown in Fig. 2 represent the highest point on the canopy. We arbitrarily selected 29 locations on different tree canopies in the image area and obtained their heights using both manual and automatic methods. The manual method was based on the image point matching through stereoscopic viewing of the stereo pair on the computer screen. This method was used as reference for accuracy evaluation because field measurement is not possible at present. Visual image matching was done in non-digital photogrammetry as a standard approach for height determination. The automatic method was based on the direct reading of the elevation data determined through the image matching algorithm. We did not measure the height at the tallest position of each tree canopy in order to assess the capability of the computer algorithm for height measurement at all possible canopy positions. Since both the 1995 and 1970 elevation data were transformed into the same UTM coordinate system, the distribution of the 29 canopy positions in the horizontal plane was kept the same for both the 1970 and 1995 data. This allows us to determine the canopy growth during the past 25 years. Table 1 shows a comparison of tree heights obtained with the 2 methods. While the absolute differences between the 2 methods can be greater than 4 m, the average differences were 1.50 m and 1.21 m for the 1970 and 1995 photos, respectively. Treating the results obtained with the manual method as accurate, the standard deviations were 1.94 m and 1.62 m for the 1970 and 1995 photos, respectively. Considering the relatively small photo scale, an error level of less than 2 m is quite reasonable. The averages of tree canopy heights for each year were very close (within 10 cm) between the 2 height measurement methods. The average growth of canopy height, derived from the averages in Table 1, was 1.54 m for the manual method and 1.43 m for the automatic method.

Table 1. Heights automatically measured from different positions of tree canopies in comparison with the corresponding heights determined by manual photogrammetric method.

Canopy position ID	1970			1995		
	Manual	Automatic	Abs. Error	Manual	Automatic	Abs. Error
	(m)					
1	9.50	9.03	0.47	10.28	8.76	1.52
2	2.33	3.91	1.57	7.92	5.19	2.73
3	10.84	7.95	2.89	9.27	8.49	0.78
4	7.09	11.73	4.64	14.69	13.07	1.62
5	8.18	8.11	0.07	9.11	9.70	0.59
6	3.20	3.98	0.78	6.32	8.17	1.85
7	7.57	7.48	0.09	7.77	8.39	0.62
8	4.99	3.20	1.79	6.55	6.28	0.27
9	9.10	7.17	1.92	9.31	8.41	0.90
10	7.33	5.54	1.78	6.62	6.79	0.17
11	4.22	1.39	2.83	3.61	3.79	0.18
12	1.78	4.22	2.44	6.61	6.00	0.60
13	7.27	5.79	1.48	6.78	6.49	0.29
14	3.07	1.19	1.88	4.66	4.14	0.52
15	7.58	6.93	0.64	2.53	5.73	3.20
16	7.45	7.07	0.38	7.65	5.85	1.81
17	2.52	3.11	0.59	4.40	7.18	2.78
18	0.80	4.76	3.96	9.88	8.38	1.50
19	5.38	5.07	0.31	6.55	2.26	4.29
20	2.61	3.64	1.03	6.28	6.71	0.43
21	4.47	4.41	0.06	13.15	12.50	0.65
22	3.12	5.92	2.80	6.61	7.72	1.12
23	8.53	7.86	0.67	7.43	6.35	1.08
24	1.00	3.28	2.28	3.26	4.40	1.13
25	2.79	2.51	0.28	3.18	3.76	0.58
26	4.50	2.47	2.02	3.32	4.02	0.70
27	6.85	8.76	1.91	10.71	10.47	0.24
28	7.64	5.86	1.78	1.65	4.44	2.78
29	6.25	6.34	0.09	6.69	6.56	0.13
Average	5.45	5.47	1.50 (1.94)[1]	6.99	6.90	1.21 (1.64)

[1]Numbers in brackets are standard deviations.

Discussions and Conclusion

Our preliminary results demonstrate the advantage of DSMs for tree height and crown closure measurement because they are not affected by crown shadow and shading caused by topographic relief. When canopy cover is relatively sparse as in this study, the ground elevation for a relatively large portion of the imaged area can be directly measured by the digital photogrammetric method. In this situation the accuracy of the entire DEM can be relatively high because we only need to interpolate over a small fraction of the landscape where scene objects such as trees obscure our direct observation of the ground. This in turn leads to a relatively high accuracy in the crown height image. However, the accuracy of a DEM determined with photogrammetric methods usually decreases as the total crown closure increases. Thus in dense hardwood stands the crown height image will be less accurate in making tree height measurements than more open stands. Nevertheless, the accuracy in estimating the change in height of trees is not affected by changes in tree crown closure because the DSMs are accurate even when the DEMs are not. In addition, the 3D crown shapes obtained from a DSM contain crown structure information that should be useful in automated tree species recognition. Some of the mathematical morphology techniques hold strong promises for application to forest type recognition (Zheng et al. 1995).

The current situation is that stereo photography lacks spectral depth, but allows for precise spatial measurements. The current generation of satellite images have more and narrower spectral bands than photographs, but are not of high spatial resolution and high geometric precision. Digital cameras bridge this gulf by providing imagery which is of both high spatial (better than 0.5 m) and spectral resolution (20 to 50 nm) with a sufficient number of spectral bands. This will enable us to develop new computational algorithms for image processing and digital photogrammetry to extract the maximum amount of information contained in aerial photographic images and to provide the parameters needed for land resource management, monitoring and ecological studies. This can provide useful approaches to evaluating changes in habitat value, rangeland carrying capacity, and tree mortality and recruitment trends.

Literature Cited

Ackermann, F. 1996. Techniques and strategies for DEM generation, p. 135–141, *In:* C. Greve, (ed.), Digital photogrammetry: An addendum to the manual of photogrammetry. ASPRS, Bethesda, Md.

Avery, T. E. and H.E. Burkhart. 1994. Forest Measurements. 4th Ed. McGraw Hill, New York, N.Y.

Bartolome, J.W. 1987. California annual grassland and oak savannah. Rangelands 9:122–125.

Biging, G.S., R.G. Congalton, and E.C. Murphy. 1991. A comparison of photointerpretation and ground measurements of forest structure, p.6–15, *In:* Proc. of the 57th Annual Meeting of ASPRS, Mar. 1991. Baltimore, Md.

Biging, G. S., M. Dobbertin, and E. C. Murphy. 1995. A test of airborne multispectral videography for assessing the accuracy of wildlife habitat maps. Can. J. Remote Sensing 21: 357–366.

Brockhaus, J. A. and S. Khorram. 1992. A comparison of SPOT and Landsat TM data for use in conducting inventories of forest resources. Int. J. Remote Sensing 13: 3035–3043.

Congalton, R., J. Miguel-Ayanz, and B. Gallup. 1991. Remote sensing techniques for hardwood rangeland mapping. Contract Rep. to California Dept. of Forest. and Fire Protection, Sacremento, Calif.

Davis, F.W., R.W. Brown, B. Buyan, and J. Kealy. 1995. Vegetation change in blue oak and blue oak/foothill pine woodland. Contract Rep. of Forest and Rangeland Resources Assessment Program, California Dep. of Forest. and Fire Protection, Sacramento, Calif.

Franklin, S.E. 1994. Discrimination of subalpine forest species and canopy density using digital CASI, SPOT PLA, and LANDSAT TM DATA. Photogrammetric Eng. and Remote Sensing 60:1233–1241.

Gong, P. and J. Chen. 1992. Boundary uncertainties in digitized maps I: Some possible determination methods, p.274-281. *In:* GIS/LIS'92, Nov. 1992. San Jose, Calif.

Gong, P., G. S. Biging, S.M. Lee, X. Mei, Y. Sheng, R. Pu, B. Xu, K.P. Schwarz, and M. Mostafa. 1999. Photo-ecometrics for forest inventory. Geographic Information Sci. 5: 9–14.

Griffin, J.R. 1978. Oak woodland, p. 384–416. *In:* M.G. Barbour and J. Major (eds.), Terrestrial vegetation of California. John Wiley and Son, New York, N.Y.

Saleh, R.A. and F.L. Scarpace. 1994. Softcopy photogrammetry: The concepts and the technology. Univ. of Wisconsin, Madison, Wisc.

Zheng, X., P. Gong, and M. Strome. 1995. Characterizing spatial structure of tree canopy using colour photographs and mathematical morphology. Can. J. of Remote Sensing 21: 420-428.