Photo Ecometrics for Forest Inventory

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Abstract

In this paper, we report the results obtained from the application of digital photogrammetry and hyperspectral data analysis for forest inventory purposes. Our long term goal is to provide low-cost yet accurate estimates of as many important forest biophysical parameters as can be measured and inferred with airborne digital cameras. Accuracies of traditional multispectral image analysis algorithms of remotely sensed data are low. Traditional photo interpretation is error prone and expensive. We propose new image analysis strategies that make use of the 3D spatial morphological information from stereo images and the multispectral, texture and contextual information inherent in the imagery.

Research on the use of 3D crown shape information in automated tree species recognition has not been reported before. The minimum requirements of image spatial resolution for deriving estimates of tree heights and crown size with high accuracies are not known. With digital photogrammetry, it has been proven that digital camera images can be georeferenced and orthorectified to an accuracy of one to several meters allowing for selecting ground control points directly from digital camera images for georectification of other images including high resolution satellite images. With the georeferenced and orthorectified digital camera images and the above parameters accurately determined, we can detect changes of species composition, height, crown closure, and diameter. These same techniques will significantly improve our ability to economically assess the accuracy of thematic vegetation maps.

I. INTRODUCTION

The need for detailed forest parameters (species, size, canopy density and numbers of trees) and other biophysical information over large land holdings in the US has increased markedly in the last five years driven in large part by the information demand for modeling forest ecosystems, identifying forest habitat locations where threatened or endangered species such as the spotted owl or marbled murrelet may occur, and by regulations requiring sustainable forest management, particularly in the West. To efficiently manage forest landscapes for forest, wildlife, and other biological resources we need to have detailed information on forest composition and structure, but it is usually economically infeasible to collect the requisite 5-10% field sample. Thus, it is critically important to be able to develop new advanced remote sensing technologies that allow for direct measurement of the parameters needed for forest management and monitoring and substantially reduce the cost of obtaining this information compared to field sampling.

We propose an interdisciplinary field, ecometrics, the science and technology of obtaining reliable ecological measurements over large landscapes. Biologists have largely overlooked the field of ecometrics because it requires skills usually outside their expertise: remote sensing, photogrammetry, statistics, and biometrics. Nonetheless development of this field is critical to provide the tools to aquatic and wildlife biologists, ecologists, foresters, and geographers to be able to measure and monitor landscape level ecosystem processes and land use changes.

This research falls in a subfield of ecometrics, photo ecometrics — the use of photogrammetry and image analysis techniques to derive ecological parameters. Figure 1 outlines the possible components of photoecometrics. The focus of this research is the development of methods for forest information extraction from high-resolution digital aerial photographs to measure important forest parameters.

Use of airphoto interpretation techniques for forest species classification and crown closure estimation is dependent on the experience of photo interpreters. Some experiments indicate that there are large discrepancies among airphoto interpretation results carried out by different interpreters (e.g., Biging et al.,

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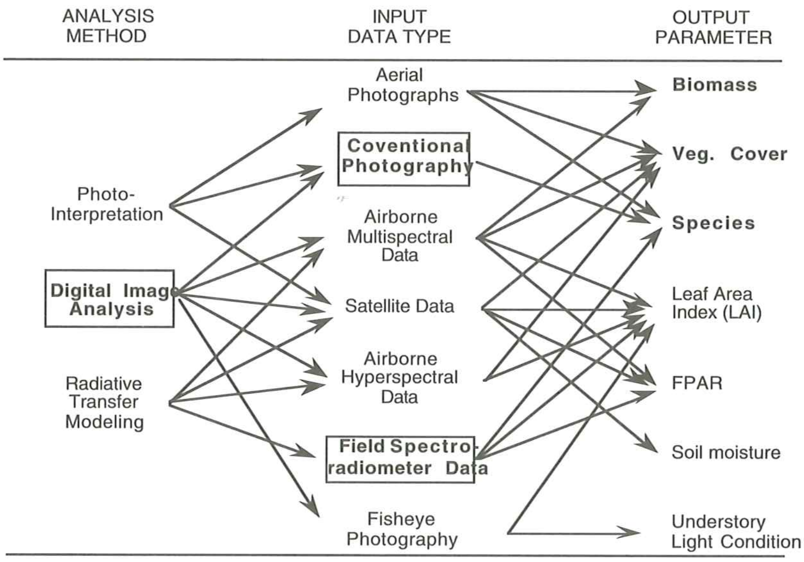

Figure 1. Possible components of photo ecometrics.

1991; Davis et al., 1995; Gong and Chen, 1992). On the other hand, it is difficult to accurately make detailed vegetation maps at the stand level with existing satellite imagery such as SPOT HRV and Landsat TM data because of their low spatial resolution ranging from 10-30 m (Brockhaus and Khorram, 1992; Franklin, 1994).

The current situation is that stereo photography lacks spectral depth, but allows for precise photogrammetric 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 and spectral resolution with a sufficient number of spectral bands. This will enable us to develop new computational algorithms for image processing and softcopy photogrammetry to extract the maximum amount of information contained in remotely sensed images and to provide the parameters needed for forest management, monitoring and ecological studies.

II. DIGITAL PHOTOGRAMMETRY FOR FOREST MEASUREMENT AND CHANGE MONITORING

Digital photogrammetry is a computerized technique that automates the measurement and mapping process of traditional photogrammetry. It includes all the procedures of traditional photogrammetry such as photo orientation, stereo model construction, aerial triangulation, contour and orthophoto generation, photo mosaicing and mapping (Saleh and Scarpace, 1994). A major challenge in digital photogrammetry is image matching, a critical procedure that finds image points from the left and right photographs that correspond to the same ground points. Although many algorithms of image matching have been suggested (Ackermann, 1996), this process is error-prone in forest and urban areas where abrupt vertical changes are common. The two primary uses of digital photogrmmetry 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 exclude the heights of landscape features such as forest and buildings. For the purpose of forest measurement, a digital surface model (DSM), an array of grid points of elevation of landscape features, is necessary. An orthophoto is a photo of an area that has a constant scale, is free from point displacement caused by elevational differences. Therefore, area measurements from orthophotos are more accurate than from raw aerial photographs.

Figure 2 shows the results from digital photogrammetry when applied to two 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, Marine County, California. They were scanned at 1000 DPI from black and white diapositives on a Vexel 3000 scanner. The digital photogrammetric software used to analyze these photos were SocetSet and VirtuoZo. Results shown here are generated automatically from digital photogrammetry. Because we did not collect ground control points, all photos were relatively orientated by assuming one of the photographs in 1970 as vertical with a scale of 1:12,000. Figures 2a, 2b shows the 1970 and 1995 orthophotos for the same area, respec-

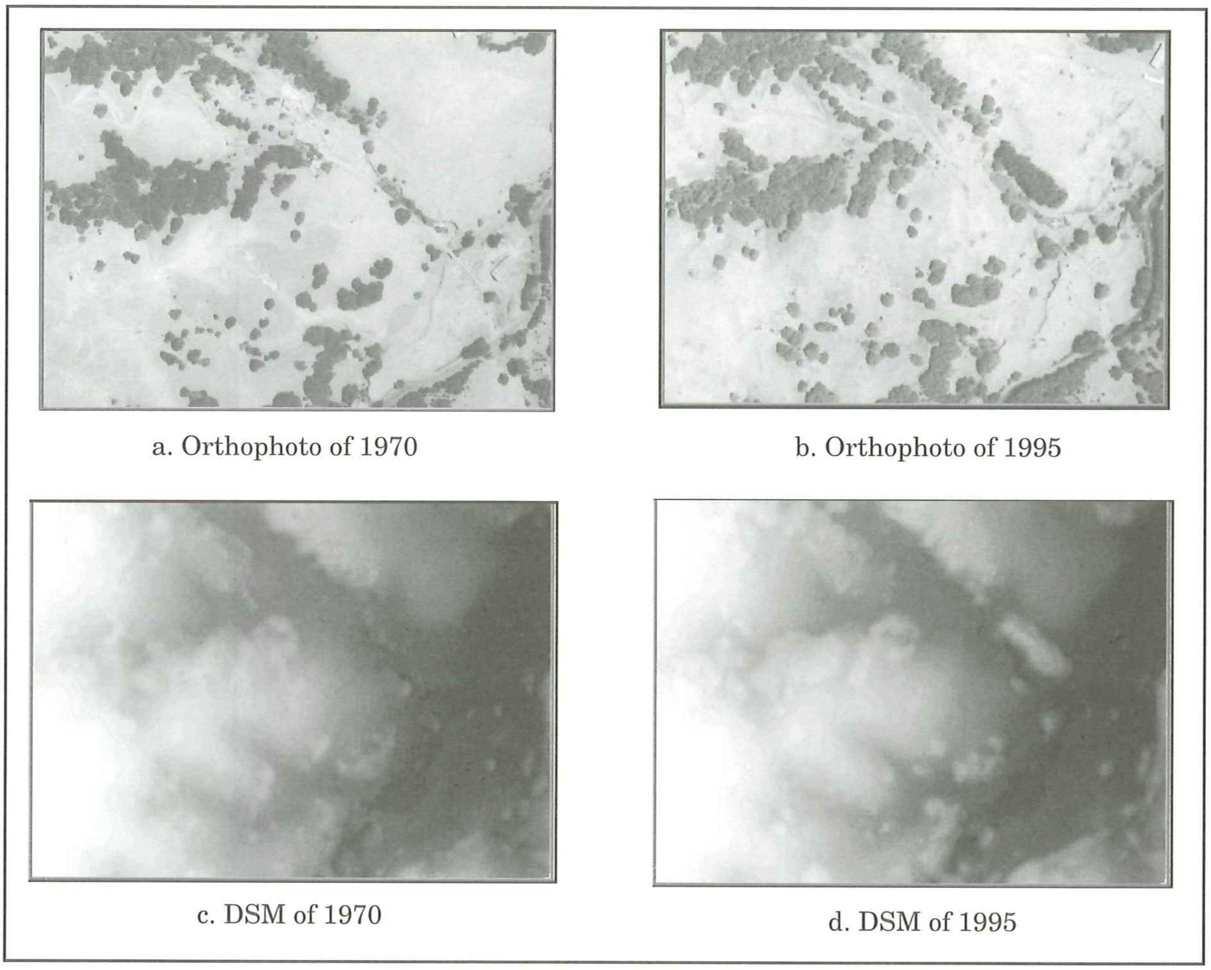

Figure 2. DSMs and orthophotos of a hardwood rangeland area. Greyscales in c and d are surface elevations.

tively. Figures 2c and 2d are the 1970 and 1995 DSMs, respectively. Figures 2a and 2b were generated by projecting the raw photo onto the 1970 and 1995 DSMs, respectively.

The scanned image resolution was approximately 30 cm. The grid spacing used to extract the DSM was approximately 1 m. The DSM shown in Figures 2c and 2d were interpolated to 30 cm. The surface cover is mainly hardwood rangeland. Clusters of relatively bright areas, in Figures 2c and 2d, are coastal live oaks. Coastal live oaks can be extracted from Figures 2a and 2b through a simple image thresholding as they are much darker then their surroundings. Changes of crown closure can be obtained by comparing the two thresholded images. Changes in tree heights can be obtained by subtracting the 1970 DSM from the 1995 DSM.

Figure 3 compares crown closure derived from the raw imagery and the orthophoto at a slightly different location. Crown boundaries are both obtained from image grey level thresholding. The boundary displacement caused by surface elevation on the raw image is obvious in an area where the elevational change is less than 60 m. The crown closure measured from the raw imagery represent a 9.9% overestimate of the actual crown closure as approximated by that measured from the orthophoto.

The lessons we learnd from experiments with aerial photographs will be used to develop algorithms for analysis of images acquired from digital aerial photography. We have integrated fully digital system with a digital camera, GPS and inertial navigation systems. A preliminary test of the system was carried out with digital photography taken over the Berkeley campus in January 1997. When the system using a 28 mm camera lens is flown at 1000 m above the ground, a georeference accuracy of 2 m in the horizontal, 3.6 m in the vertical direction can be achieved (Mostafa et al., 1997). This implies that the system can locate points on the ground with 2-3 m accuracy with no need of any ground control points in the area of interest.

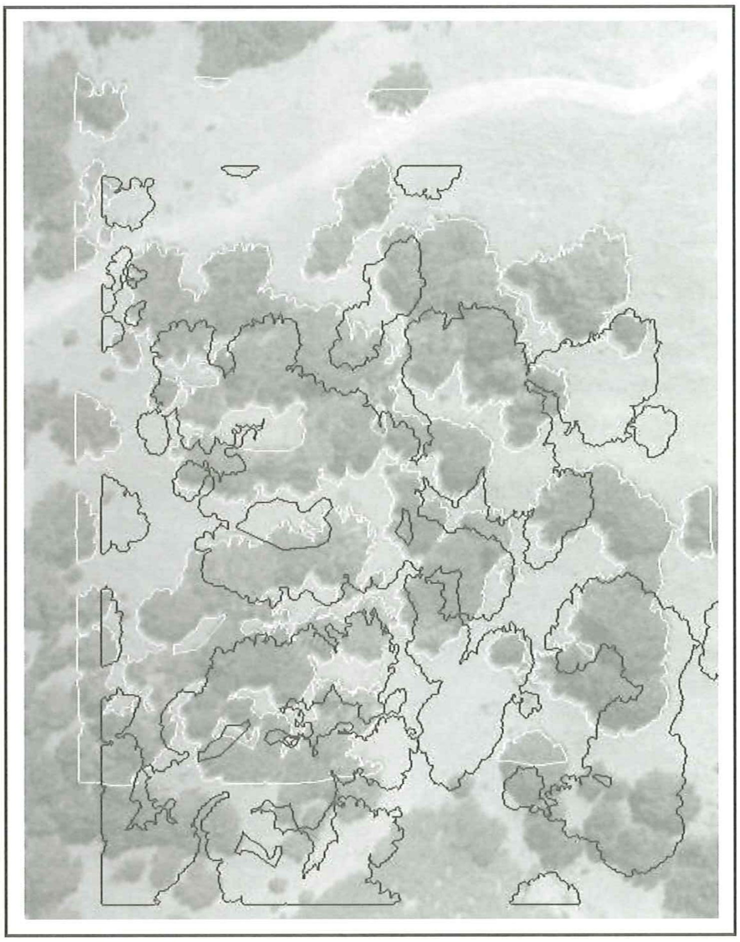

Figure 3. Crown closure boundaries extracted by image thresholding. White lines were derived from the orthophoto, while the black lines were obtained from the raw imagery.

III. TREE SPECIES RECOGNITION

This is difficult in traditional remote sensing image analysis. With experience gained in the application of neural networks from some previous studies (e.g., Gong, 1996; Gong et al., 1996), we evaluated its potential in classifying 6 conifer species based on hyperspectral data collected using an Ocean Optic® portable hyperspectral radiometer. The 6 conifer species are typical in the Serria Nevada mountains in California. Our measurements were collected in the field from 4-7 year old trees at the Blodgett Forest Research Station operated by the Department of Environmental Science, Policy, and Management at the University of California at Berkeley. With approximately 4500 acres of conifer forest land, this site is located in the American River watershed on the western slope of the Sierra Nevada in El Dorado County of California. Main conifer species of northern California include giant sequoia, Douglas-fir, white fir, ponderosa pine, sugar pine and incense cedar, of various ages.

Our recent analysis of hyperspectral measurements taken from six conifer species at the Blodgett Forest has produced excellent results in tree species separation. With spectral derivative applied to the hyperspectral measurements and the use of a feed-forward back-propagation neural network algorithm, we consistently obtained better than 80% accuracies of discriminations of the six conifer species at several sites in either summer or late fall seasons (Gong et al., 1997). Discrimination accuracies for the six species at some sites exceeded 90%. These results are helpful to our band selection effort.

In a recent study, we applied six types of transformation to the hyperspectral reflectance data (R), preprocessed with a simple smoothing, followed by band merging. These include LOG(R), first derivative of R, first derivative of LOG(R), normalized R (N(R)), first derivative of N(R), and LOG(N(R)).

Table 1 lists overall accuracies in percentage obtained from classifying each of the 12 sets of data (2 sides of canopy X 2 sites X 3 seasons) by neural networks. The neural network structure and parameter settings are approximately the same as those presented in Gong et al. (1997). The averages of overall accuracies for the sun-lit and shade sides of canopies have been listed at the right end of the table. The average overall accuracies exceed 90% for data collected from both the sun-lit and shade sides of canopies. The average of sunlit and shade accuracies is 91.3%. The best transformation method seems to be the one taking the derivative after taking the logarithm. This is closely followed by the method of taking the derivative after normalization, which yielded an average of all accuracies of 90.1% and taking the derivative alone, which yields an average of all accuracies of 85.3%. The three top ranked transformation methods produce average accuracy improvements of 23%, 21.8% and 17%, respectively, over the 68.3%, the average of all accuracies obtained from the original data without transformation. Taking the logarithm alone resulted in a decrease of 3.9% in average of all accuracies. Conducting the normalization alone or taking the logarithm after normalization resulted in small accuracy improvements.

Comparing the accuracies obtained from derivative spectra with corresponding non-derivative spectra (D(R) vs. R, D(LOG(R)) vs. LOG(R), and D(N(R)) vs. N(R)), we can see that taking the derivative has greatly improved classification accuracies. Most of the accuracy improvements are between 15-30%, while some are greater than 36%. In one instance a decrease of 0.7% was obtained between D(R) and R for the measurements collected from the shade sides at the Fenced site in June 1996.

From the above analysis, it can also be seen that the effect of hyperspectral data taken from the shade sides of tree canopies can be minimized by applying normalization or by taking the derivatives after applying a logarithm to the preprocessed data. A big difference in solar angle did not cause a noticeable difference in accuracies of species recognition.

Table 1. Percent species recognition accuracies using spectral reflectance measurements collected from sunlit and shade canopies of individual trees at two sites and 3 time periods at the Blodgett Forest.

Transform	G site 10/95		F site 10/95		G site 6/96		F site 6/96		G site 11/96		F site 11/96		Average		
types	Sunlit	Shade	Sunlit	Shade	Sunlit	Shade	Sunlit	Shade	Sunlit	Shade	Sunlit	Shade	Sunlit	Shade	Overall
R	70.8	59.2	58.3	35.0	75.8	65.3	81.9	90.3	74.2	60.8	75.0	73.3	72.7	64.0	68.3
D(R)	85.0	95.8	65.0	45.0	90.8	81.7	93.1	89.6	95.8	97.6	94.2	90.0	87.3	83.3	85.3
LOG(R)	60.8	55.8	50.8	41.7	78.3	60.0	77.8	89.6	60.1	65.7	60.8	70.8	64.8	63.9	64.4
N(R)	65.8	64.2	51.7	42.5	72.5	66.7	84.0	91.7	79.8	78.4	76.7	80.8	71.8	70.7	71.2
D(LOG(R))	91.7	94.2	79.2	64.2	93.3	92.5	97.2	97.9	96.6	99.2	93.3	96.7	91.9	90.8	91.3
LOG(N(R))	63.3	60.0	48.3	43.3	71.7	65.0	85.4	93.8	76.5	71.8	75.0	79.2	70.0	68.8	69.4
D(N(R))	93.3	93.3	80.8	56.7	91.7	85.0	95.1	95.1	98.3	97.6	97.5	96.7	92.8	87.4	90.1

IV. CONCLUSIONS

Digital photogrammetry has the advantage of supplying 3D information from stereo aerial photographs for subsequent analysis. We demonstrated that this information is useful in estimating tree heights, removing feature displacement in the image and thus leading to more accurate crown closure estimation. We will further test its potential in distinguishing shaded tree canopies from background shadows, and the use of tree canopy shapes in species recognition. Our analysis of *in situ* hyperspectral measurements has indicated that the six conifer species can be discriminated with neural networks at an accuracy of greater than 90%. Taking the derivative of the hyperspectral data, or taking the derivative after the logarithm or after the normalization of the hyperspectral data promise satisfactory species recognition results. These transformation methods are not sensitive to solar elevation changes. Further research will be directed to optimal band selection and apply the optimal spectral bands to digital photography. The combined strength of high spatial resolution digital aerial photography and high spectral resolution optimal band setting will be evaluated in the context of forest species recognition and measurements.

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