Imagery Data Processing System Using Aerial Photography for Sensitive Site Investigations in the Route Selection Process

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ABSTRACT

A route selection consists of engineering, biophysical and socio-economic components. A road will generate constraints in one or more of these components. The road proponent then must present the advantages and disadvantages of alternative proposals, the rationale of choosing a particular route and the trade-off made (unavoidable impacts requiring protection planning) on the basis of the best balance and/or the equitable compromise between the engineering, biophysical and socio-economic components. Aerial photography has developed into a standardized, technically mature tool for aerial photo interpretation, reconnaissance and inventory. Traditional procedures of photogrammetric data gathering characterized by interdisciplinary methods, however, may be insufficient to address all of today's environmental protection issues regarding the road planning phase. New scanning sensors and automated imagery data processing software to identify site investigation data in a detailed spatial context have recently become affordable.

In this paper, the present phase of a PC-based imagery data processing system using aerial photography through the application to preliminary road network plans in Mie University forests has been summarized, and some prospective role discussed.

Keywords: *forest road, environmental impacts, orthophotograph, sensitive site components, overlay analysis.*

INTRODUCTION

Planning, environmental and engineering guidelines for road development are necessary for the orderly development and protection of natural resources. Road development is one of the most environmentally damaging activities in forest areas and often leads to serious and unnecessary degradation of natural resources. At present, there are no uniform environmental and engineering design standards for single and/or multiple purpose roads. Roads that have originally been for one purpose are very often later used and upgraded for another purpose. The initial road planning phase therefore becomes very significant if the total infrastructure that may later develop is considered.

A route selection consists of engineering, biophysical and socio-economic components. A road will generate constraints in one or more of these components. The road proponent then must present the advantages and disadvantages of alternative proposals, the rationale for choosing a particular route and the trade-off made (unavoidable impacts requiring protection planning) on the basis of the best balance and/or an equitable compromise between the engineering, biophysical and socio-economic components. A thorough routing study is a multidisciplinary undertaking. Routing objectives have to be established for each component affected during project conceptualization.

Those responsible for the engineering component may establish such objectives as minimizing cost and providing a well-designed facility. Those responsible for the biophysical component would have the objectives of avoiding disturbance to sensitive parts of the environment and minimizing disturbance to, or interference with, other existing or planned land/water resource uses. Similar objectives may be established for the socio-economic component, when planning routes in populated areas [18].

Route selection has two distinct phases: regional study and detailed route selection. Regional study identifies broad, feasible corridors. These corridors are wide, elongated land areas selected for broad resource capabilities, uses and potential impacts. One or more corridors are selected for a detailed evaluation of their potential for routes on the basis of the best balance between the biophysical, socio-economic and engineering components. Detailed route selection, carried out in greater detail, selects one or more routes within the preferred corridor(s) selected by regional study. The components of route selection are analyzed in detail for each selected corridor according to the potential impacts that must be avoided and those that can be suitably mitigated.

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The routes and route alternatives are identified within each corridor followed by further analysis involving detailed aerial photo interpretation, aerial reconnaissance and ground check. Environmental impacts are identified during the route selection process. Detailed plans show the location of resources affected and quantify potential environmental concerns. The level of detail required in plan preparation depends on the amount and degree of impact created by the proposed road. In general, the higher the class of road and the greater the engineering that goes into the design of the road, the greater the need for in-depth planning [16].

Aerial photography is the primary source of information for much of the road planning and resource inventory activities undertaken in modern forest management. Aerial photography has developed into a standardized, technically mature tool for aerial photo interpretation, reconnaissance and inventory. Traditional procedures of photogrammetric data gathering characterized by interdisciplinary methods, however, may be insufficient to address all of today's environmental protection issues concerned with the road planning phase, which claims detailed, site-specific, carefully timed quantitative and qualitative information. Aerial photography as a type of analogous memory medium may not represent meaningful information: it is comparatively difficult to discern the specified anomalies or site-specific target conditions in relation to the complex interactions between different landscape components of ecological and hydrological characteristics on aerial photographs [2]. New scanning sensors and automated imagery data processing software to identify site investigation data in a detailed spatial context have recently become affordable.

In this paper, the present phase of a PC-based imagery data processing system using aerial photography (Table 1 and Figure 1) through the application to preliminary road network plans in Mie University forests has been summarized, and some prospective roles discussed.

The approaches are illustrated using examples of (1) digital classification of land cover and interpretation-accuracy measure by discriminant function analysis, (2) area measurements using a pixel-based aggregation technique, and (3) overlay analysis through linking an imagery data processing system to TERDAS software.

Table 1. Hardware and software configuration.

IBM AT compatible PC; 16Mb RAM/800Mb hard disk
MS-Windows 3.1
Epson color image scanner; 400 dpi Epson color inkjet printer; 720 dpi Canon laser beam printer; 600 dpi Graphtec digitizer; 950 x 645 mm
Adobe Photoshop 3.0j

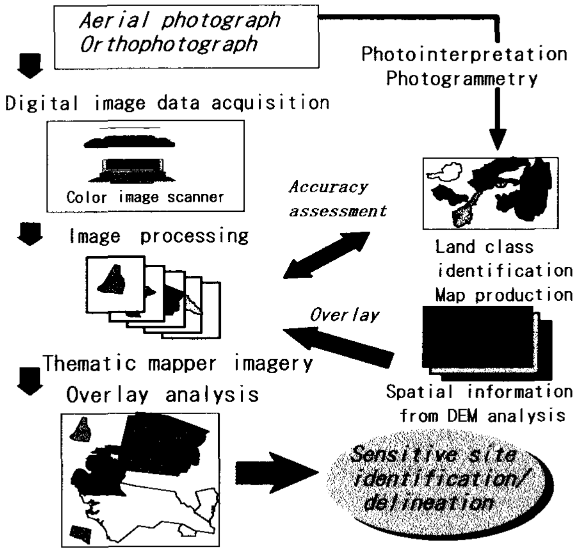


Figure 1. Procedure for imagery data processing using aerial photography.

PROBLEM FORMULATION

Remote sensing has been widely identified as being of considerable importance in many areas of environmental management. Aerial photography at altitudes, airborne- and satellite-borne multispectral scanners, infrared scanners and radar are remote sensing systems that can be useful in forestry and forestry-related activities. Each of these systems has a unique sensitivity to portions of the electromagnetic spectrum. Portions of the electromagnetic spectrum most useful in forest resource management include the ultraviolet (0.28-0.40 μ m), visible (0.4-0.7 μ m), photographic infrared (0.7-0.9 μ m), near infrared (0.9-1.3 μ m), middle infrared (3.0-13.8 μm) and microwave (0.1-77.0 μm) [4,9]. Unfortunately, problems of cost and complexity have keep it a relatively esoteric technology with limited use by most environmental resource managers. Existing airborne multispectral systems (MSS) are few in number and expensive. In addition, they require more expensive, relatively larger aircraft then are generally used for conventional photo surveys. Additionally, most existing systems are data collection systems that do not normally have analytical capability at a local level platform in forestry. Airborne multispectral scanning instruments are expensive "high tech"- systems that require expensive aircraft and specialized system operators. For practical resource management purposes, the costs of using airborne scanners could exceed the budget and potential benefits of the remote sensing data in many projects.

Although the Landsat Thematic Mapper (TM) has provided improved spatial and spectral resolution for synoptic small-scale images, Landsat tapes are still expensive for the small user and 30 m orbital resolution is unsatisfactory for many practical applications. Under many circumstances Landsat remains an experimental satellite with limited resource management utility. Spot is now providing orbital data with improved spatial resolution, but for many applications large-scale airborne data are necessary to provide suitable resolution.

Aerial photographic interpretation remains the most common remote sensing technique. In fact, many users of aerial photography as well as satellite imagery seldom do more than view and interpret the most obvious features using the image as a photo map. For many monitoring purposes, this has proved to be satisfactory, and research groups and agencies will contract aerial photography for this type of documentary purpose. Aerial photography may be satisfactory for some applications, but the costs of commercial metric photography, and especially colour and multispectral packages, often exceed budget limitation.

As a result of the relatively high cost for metric photography, there has been increasing interest in PC-based imagery processing systems as well as small-format camera systems and airborne multispectral video (MSS) systems [3]. With over a decade of experience in digital analysis of multispectral Landsat data, analytical image processing procedures have become widely accepted and well-known. Since about 1980, microcomputer-based (e.g. 80386) systems have become widely available and are relatively inexpensive. The use of colour digital scanners on such systems is common. This has permitted considerable flexibility in data capture. For example, colour and colour infrared aerial photographs are easily digitized using colour separation filters, although there is some loss of spectral information when using colour separations from colour photographs [6]. With the availability of inexpensive PC-based digital imagery processing systems, the use of aerial photography is now being reconsidered as a viable alternative for spatial information acquisition beyond the capability of the sophisticated aerial photo interpretation depends to a large degree on the training, experience, and knowledge of the interpreter, and the performance capabilities of the analysis equipment [10, 11].

The low costs of PC-based analytical systems with peripherals such as colour image scanner, digitizer and colour printer, use of aerial photographs in abundant supply and relatively simple operating requirements, provide a system that can be project-dedicated or kept on stand-by without becoming cost prohibitive. Such processing of photo-based digital image data used in conjunction with aircraft positional information will permit an intelligent system to automatically sense specified anomalies or target conditions for resource management teams.

CHARACTERISTICS OF ORTHOPHOTOGRAPHY AS INFORMATION SOURCES

An orthophotograph is a standard aerial photograph that has complete differential rectification which corrects for (1) original camera distortion, (2) tilt or tip at the instant of exposure and (3) displacements due to terrain relief. The resulting image is in true orthographic position. In other words, an orthophotograph is a photograph on which image positions have been adjusted so that they are "map correct."

The advantage of an orthophotograph is the addition of a photographic image in true map location. Therefore, many applications of orthophotographs are related to this feature. Timber or cover class delineation, wildlife habitat, fire hazards, insect damage, and fire damage interpreted on aerial photographs are transferred to an orthophotograph for more effective use of that data. An orthophotograph is also useful for planning recreational developments, timber sales and road layouts because both linear and area management can be made directly on the photo image. Some orthophotographic production systems create digital elevation data as a by-product. These data can be used in computer systems to design road and logging systems, maps, and perspective views for environmental analysis. Some disadvantages of orthophotography and orthophoto maps are (1) orthophoto images are degraded from the original aerial photograph, making them poor for interpretation work, (2) the cost of an orthophoto image is higher than standard aerial photographic prints, and the production of an orthophotograph takes much longer than the production of a contact print or enlargement made from a standard aerial photo negative.

SOME PRACTICAL APPLICATIONS

Outlines of the Study Area

Mie University forest (total area: 457 ha) is located in the headwater zone of Kumozu River and stretches 4km east to west and 1.7 km north to south in a rectangular shape (Figure 2). The area is characterized by high relief with altitudes ranging from 500 m to 1200 m above sea level. Mesozoic strata comprising Biotite-hornblende granodiorite rocks, which are easily collapsed by rainfall, are widely distributed. Landslides occurring along a fracture trace of irregular surface and bare sites on side slopes of ridges are scattered all over the area. Predominantly fine-grained cohesive soils derived from weathered sedimentary rocks are generally shallow. The average annual temperature is 12.4°C and the annual precipitation is 2517 mm (1980-1992). The forest consists of natural and artificial forests in the proportion of 6 to 4. Natural forests (total area: 262.4 ha) are mixtures of coniferous and deciduous broad-leaved trees and are significant for their watershed, landscape and wildlife habitat, so harvesting activities in these areas are, in principle, prohibited. A greater part of the artificial forests (total area: 162.2 ha) composed predominantly of *Cryptomeria japonica* (Japanese cedar) and *Chamaecyparis obtusa* (Japanese cypress) are located on steep slope terrain and the stands are occupied by fairly young immature trees.

Opening-up measures are therefore needed to protect watershed, landscape and wildlife habitat upstream, and small-scale selective cutting systems combined with cable yarding methods are practiced for timber harvest in the artificial forests. According to the ninth-term management program (1988-1992),

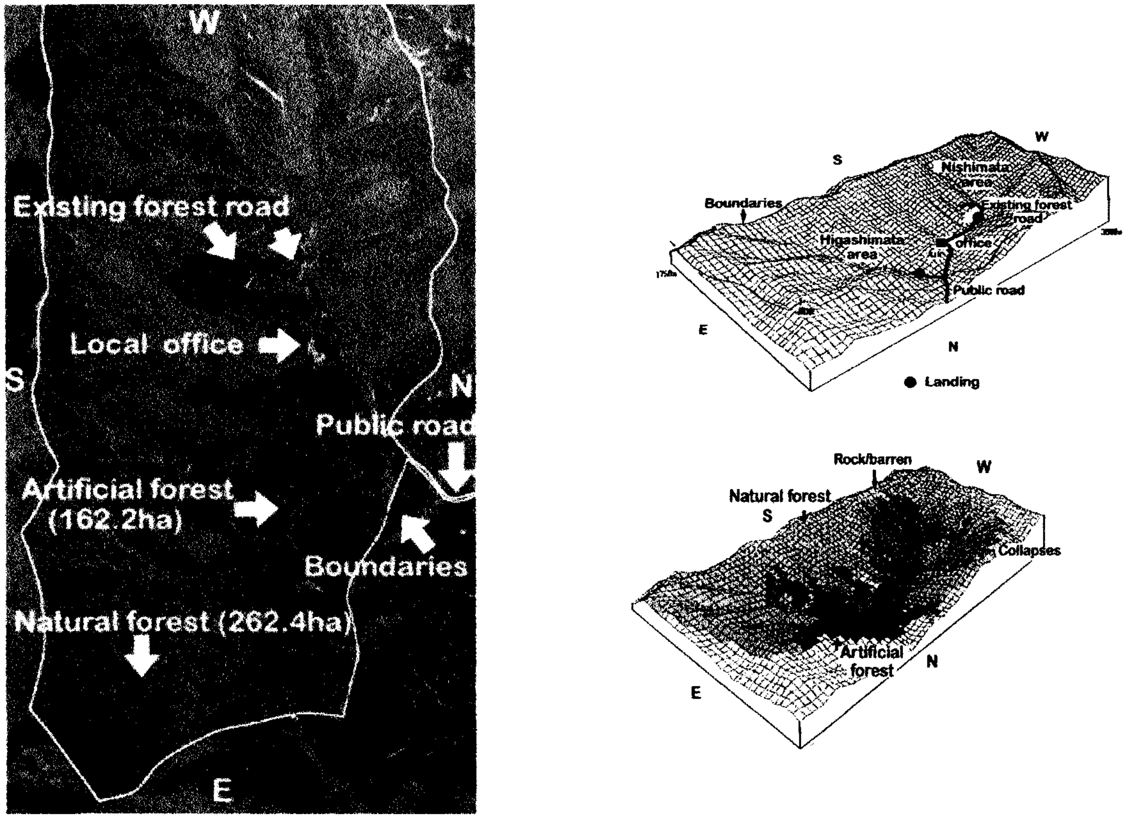


Figure 2. Mie University forests (orthophoto image at a 1:10,000 scale and terrain block diagrams with land attributes).

which is renewed every five years, the annual timber production accounts for 72 m^3/ha of final cuttings and 9.96 m^3/ha of thinning respectively. The opening-up areas are delineated by two major drainage basins called "*Nishimata*"- in the western part and "*Higashimata*" in the eastern part. Existing forest roads (total length: 1176 m) constructed with second class standards (road surface: 3 m; gradients: 12%; minimum radius of curve: 8 m; design speed: 20 km/ha) extend from both landings to each opening-up area. The development plan requires early extension of the road networks. Engineering problems concerned with opening-up measures include (1) insufficient accessibility with the existing forest road extension to keep the yarding distance within 200 m and lower standards of constructed roads, (2) operational restrictions due to terrain and seasonal weather conditions, and (3) less freedom of possible route alternatives due to the presence of reserved forests, erosion hazard sites and buffer zones around streams [16].

Digital Classification of Land Cover and Interpretation Accuracy Measure

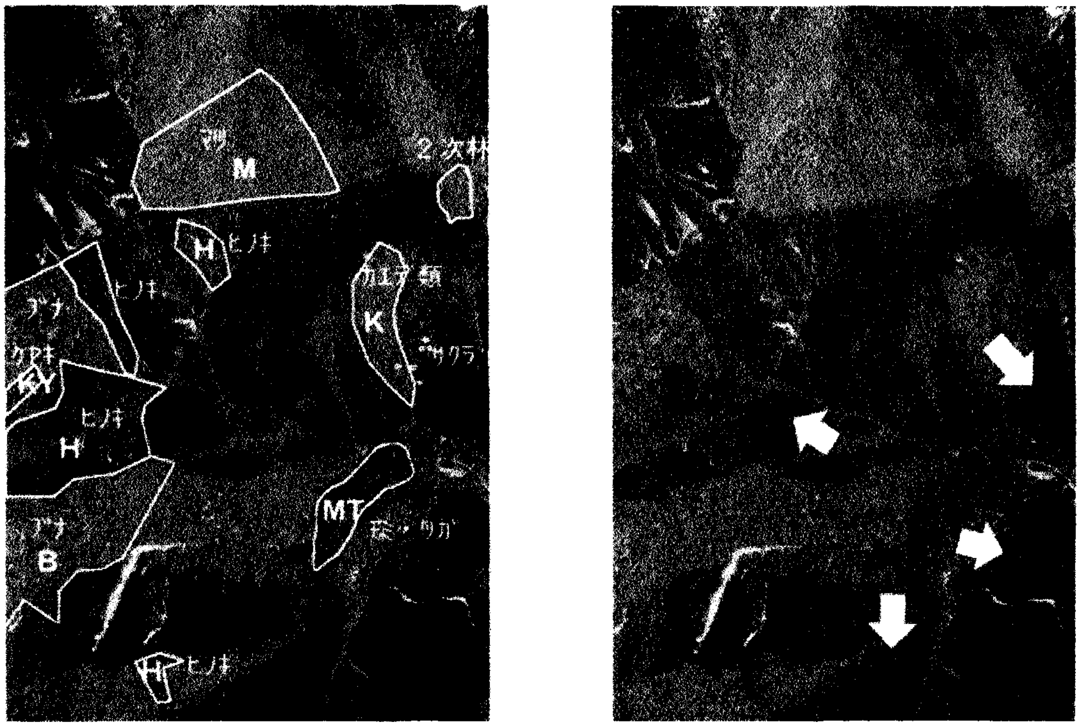
The purpose of this section is to assess whether required information such as land use and stand covers could be obtained from digital imagery interpretation and also whether the digital processing system could improve visual interpretability through aerial photo interpretation. There was pre-experimentation with a number of different film types, photo scales and interpretation techniques to find the combination that would produce the best results [8,13]. The pilot study resulted in the choice of a true colour aerial photograph of a standard 9 x 9 inch format for visual photo interpretation and an enlarged medium-format orthophoto (50 x 75 cm; scale 1:5,000) for imagery data processing respectively. Aerial photographs were taken 21 May 1993 between 10:00 a.m. and 12:30 p.m. from a 4,200 m altitude; sun angle=65°-42'-08", azimuth=239°42'.

The first step of photo interpretation was to separate forested from nonforested lands. Forested land was then classified as natural or artificial. Stand cover types were identified from a minimum stand size of 0.25 ha. Nonforested land included cutbank, rock and barren, and collapses. Areas that were difficult to interpret (derived from incorrect typing etc.) were defined as "gray zones" [1]. Gray zones were identified on the photo, and ground check work was carried out in the field. Consequently, cover types were classified into six categories as collapses, Japanese cedar, Japanese cypress, Siebold's beech, Zelkova, or mixed Momi fir and Japanese hemlock. After the final photo interpretation was completed, cover type boundaries were overlaid on the orthophoto image.

An orthophoto image was digitized to eight-bit resolution and digital classification for 87 training samples selected was carried out using a PC-based Photoshop imagery processing system. The minimum area of training samples (delineated by polygons) ranged approximately from 0.023 ha in high-density stand covers to 0.25 ha in low density stand covers. Delineation of cover types was conspicuous on photo imagery with the highest contrast. It was easy to distinguish coniferous from deciduous species (Figure 3). Within these groups, further colour differences considered in association with textural differences and crown sizes permitted a very accurate delineation of species.

Figure 4 shows an example of separability plots between four classes assigned to RED and GREEN CCT's: centerpoint=mean, radius=standard deviation. The figure indicates that forested and nonforested (collapse) areas are easily differentiated and that there is a reasonably strong linear relationship between RED and GREEN CCT levels. In order to select from RGB the CCT triplet of false colour allotment which provides maximum information for the display of a colour composite, the appropriate CCT level was calculated using descriptive statistics [19].

Figure 5 shows Box-and-Whiskers plot of average measurements of RGB CCT levels. The results correspond with the contrast information on above simple detection; RED and GREEN have the closest CCT characteristics to forested or nonforested areas and they perceive slight differences between CCT's in six classes, while BLUE has some difficulty in distinguishing the target stand type between forested areas because of relatively slight differences between CCT levels.



Aerial photo interpretation

Digital image interpretation (Japanese cedar)

Figure 3. Example of both aerial photo and digital image interpretation.

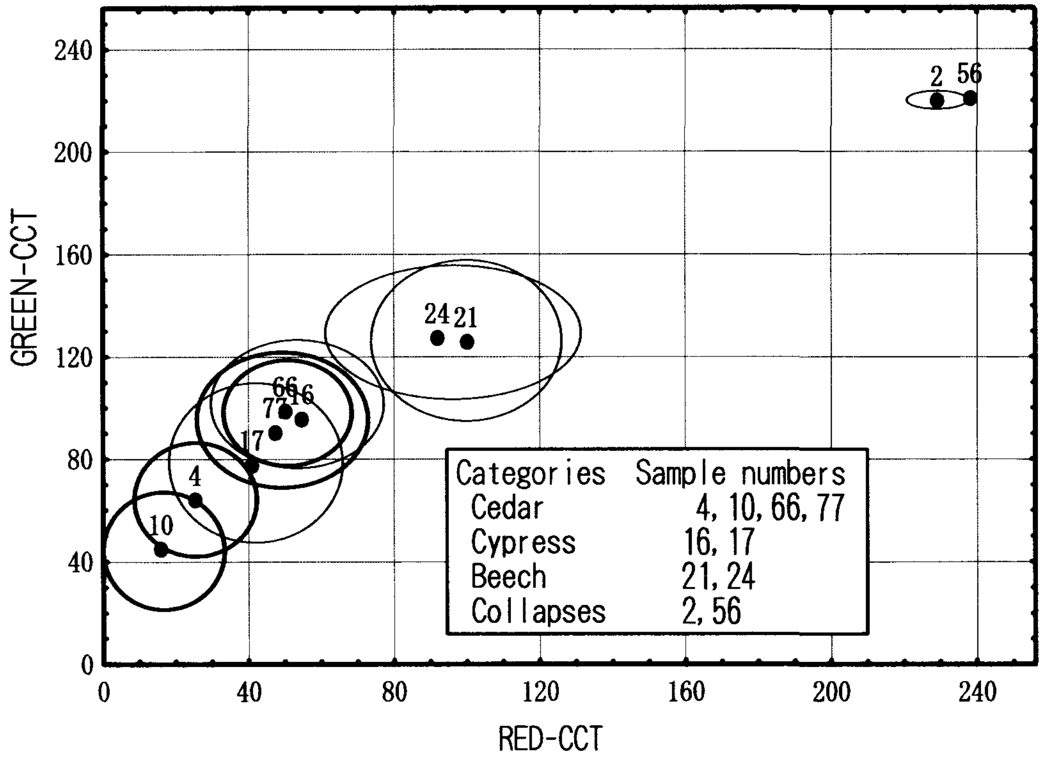
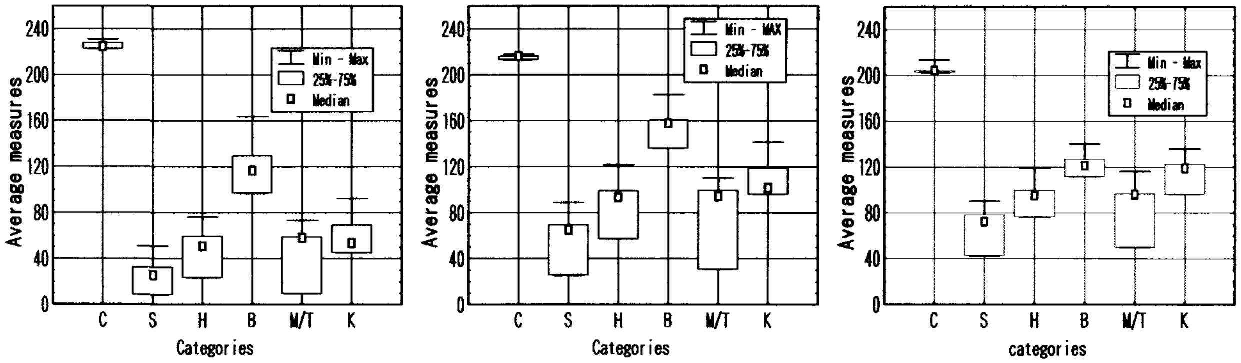


Figure 4. Separability plots between categories assigned to RED and GREEN CCT: centerpoint = mean, radius = standard deviation.



RED

GREEN

BLUE

Figure 5. Box and Whiskers plot of average measurements.

Discriminant function analysis is a very useful tool for detecting the variables that allow one to discriminate between different groups. The purpose of analysis here is to demonstrate how the system can discriminate between the six types of photointerpreted covers. Table 2 gives summary results of the prediction. The table indicates the number of training samples that were correctly classified (on the diagonal of the matrix) and those that were misclassified. Also shown in the first row of each column header are the "a priori" classification probabilities. As we can see, 73.26% of all training samples are classified correctly in this case (overall interpretation accuracy): 100% of the collapses; 66.67% of the Japanese cedar; 40% of the Japanese cypress; 86% of the Siebold's beech; 92.3% of the Zelkoba; and 60% of the mixed Momi fir and Japanese hemlock are correctly classified. Most errors occur between coniferous species, such as Japanese cedar, Japanese cypress, and mixed Momi fir and Japanese hemlock. The reason for this misclassification lies in the fact that subtle changes in RGB color do not always translate into significant variations in appearance, although there are slight colour differences associated with textural differences, crown size and crown density within these species.

An overall accuracy of 73.26% may be acceptable for preliminary interpretation [13].

Area Measurements

Accurate estimations of the area are important for forest management and planning. Areas on the photograph can usually be obtained with planimeters, dot grids, digitizers, or directly from the stereomodel using PC-based analytical stereoplotters [5]. Areas of a defined portion on digital photo images can be determined by the number of composite pixels: ASA (aggregated surface area measured by pixel counts) [7, 13].

This method was applied to the area measurements of 28 compartments/subcompartments of the University forests. Also orthophoto-based area measurements with a digitizer were carried out for "photo truthing": PSA (planimetric surface area measured on orthophoto). The measurement result is given in Figure 6. The figure indicates that the measurement accuracy of both ASA and PSA is almost of same order. This results in a flexible digital imagery processing system that can be used for linear and/or area measurements on photo imagery.

Table 2. An error matrix of interpreted training samples based on discriminant function analysis.

C:Collapses S:Japanese cedar H:Japanese cypress B:Siebold's beech K:Zelkova
M/T: Mixed Momi fir and Japanese hemlock

Rows: Observed classifications
Columns: Predicted classifications
p-value: Priori probabilities

	Producer accurary (%)	C p=.15116	S p=.17442	H p=.17442	B p=.17442	K p=.15116	M/T p=.17442
C	100.00	13	0	0	0	0	0
S	66.67	0	10	3	0	0	2
H	40.00	0	3	6	1	0	5
B	86.67	0	0	1	13	1	0
K	92.31	0	0	0	0	12	1
M/T	60.00	0	3	2	1	0	9
Overall interpretation accuracy (%)							
	73.26	13	16	12	15	13	17

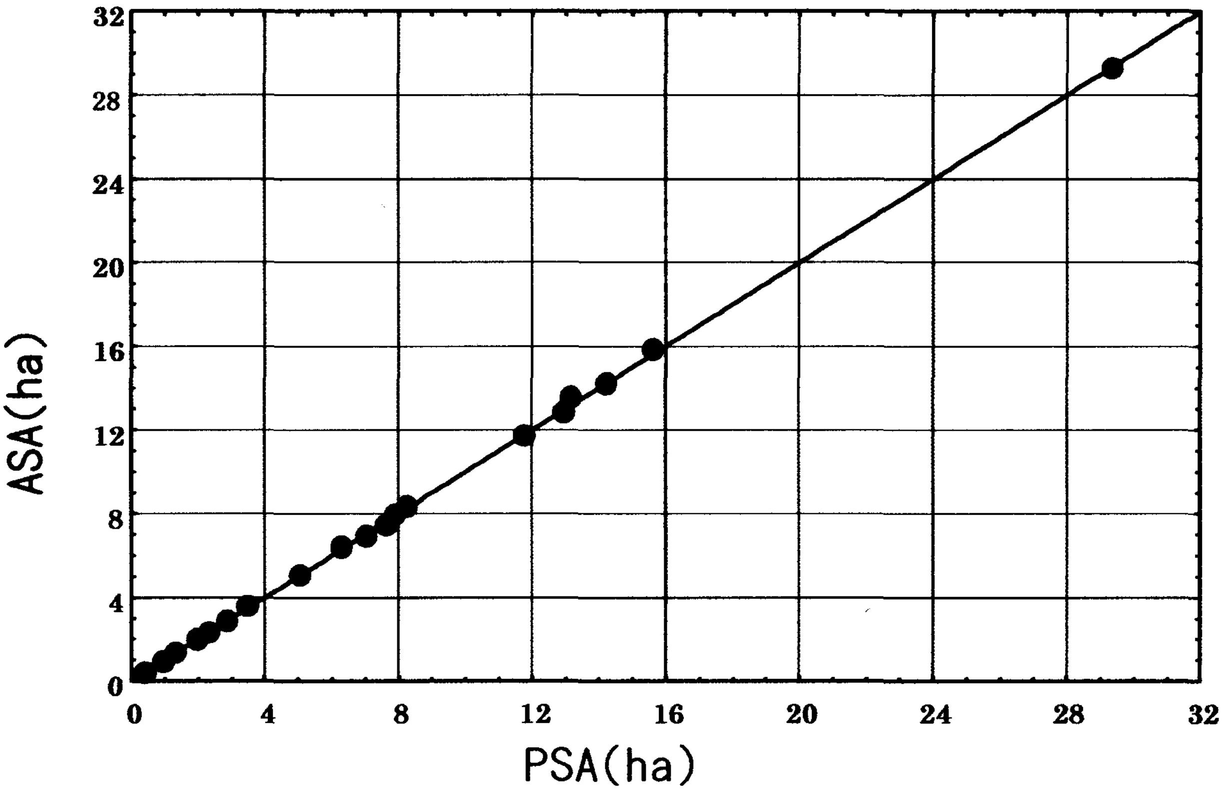


Figure 6. Comparison between *ASA* (aggregated surface area measured by pixel counts) and *PSA* (planimetric surface area measured on orthophoto).

Overlay Analysis: Linking the Imagery Data Processing System to TERDAS Software

Extracting specific information from a data layer and combining it with other information from that or another data layer depends on the use of Boolean algebra, in which the operators "AND," "OR," "XOR," and "NOT" manipulate spatial data by testing to see if a given condition or statement is true or false. Then data layers can be combined to form a new layer. For example, to find all locations where vegetation type "B" exists with slope class"C", and with the presence of aggregated drainage area "D", one would simply use the statement "B" AND "C" AND "D". Map "E" would indicate all locations where this statement was true.

The purpose of the last section is to demonstrate overlay applications that link a Photoshop imagery data processing system to TERDAS (Terra-database system) software associated with the identification of sensitive sites influencing route locations. TERDAS is a software package for integrated timber harvest/ route location planning. It was developed for a PC-based, interactive graphic system, and includes programs for terrain analysis, stream network analysis, simulation analysis of shadow patches of sunlight distribution, bedding boundary simulation, buffering, and overlay analysis [14, 15, 16, 17].

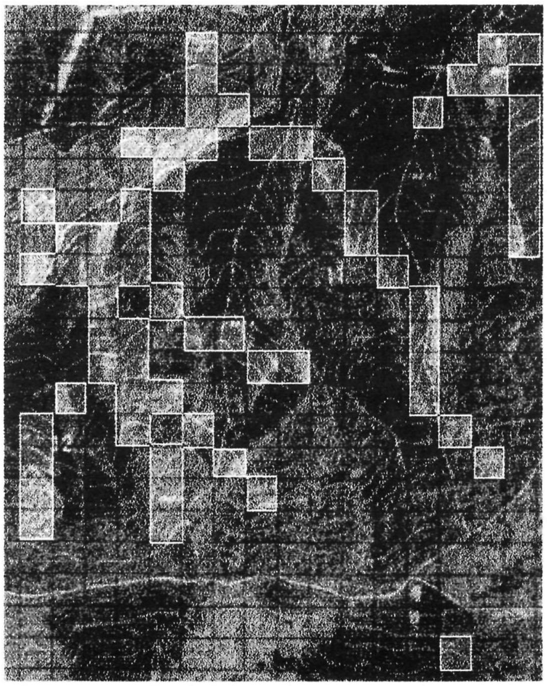


Figure 7. Orthophoto image overlaid with aggregated drainage areas of 1 ha.

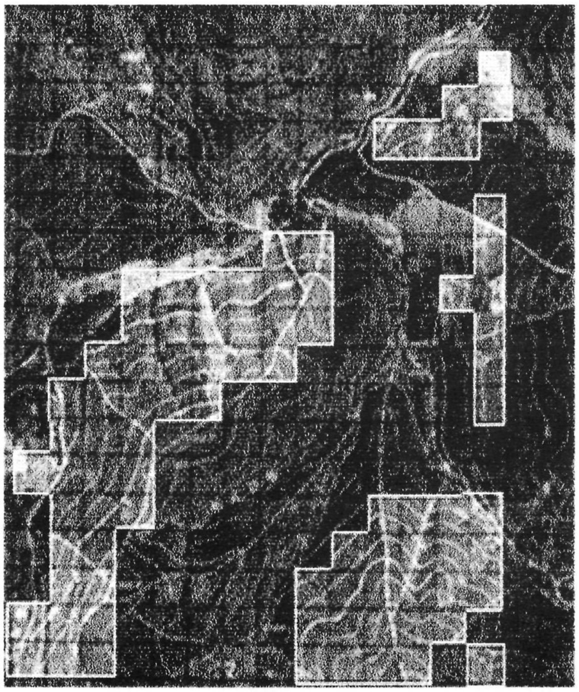


Figure 8. Orthophoto image overlaid with shadow patches of sunlight.

Figure 9. False colour image of stream lines/drainages.

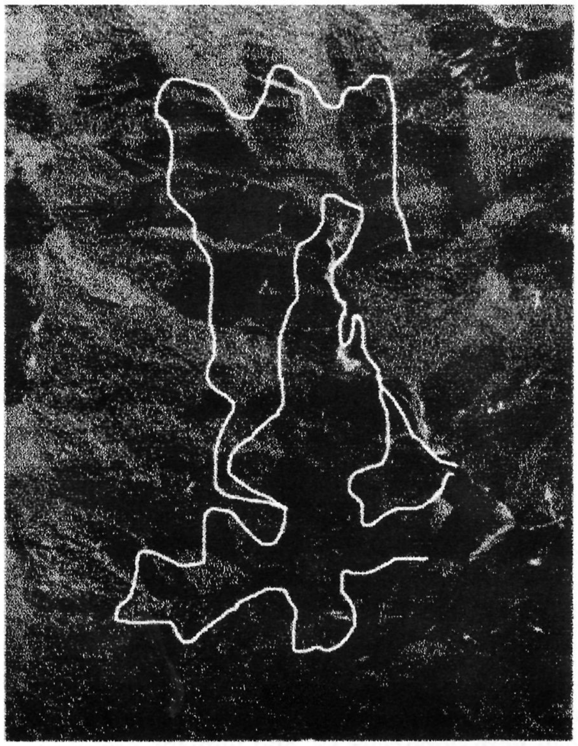


Figure 11. Proposed road layout alternatives.

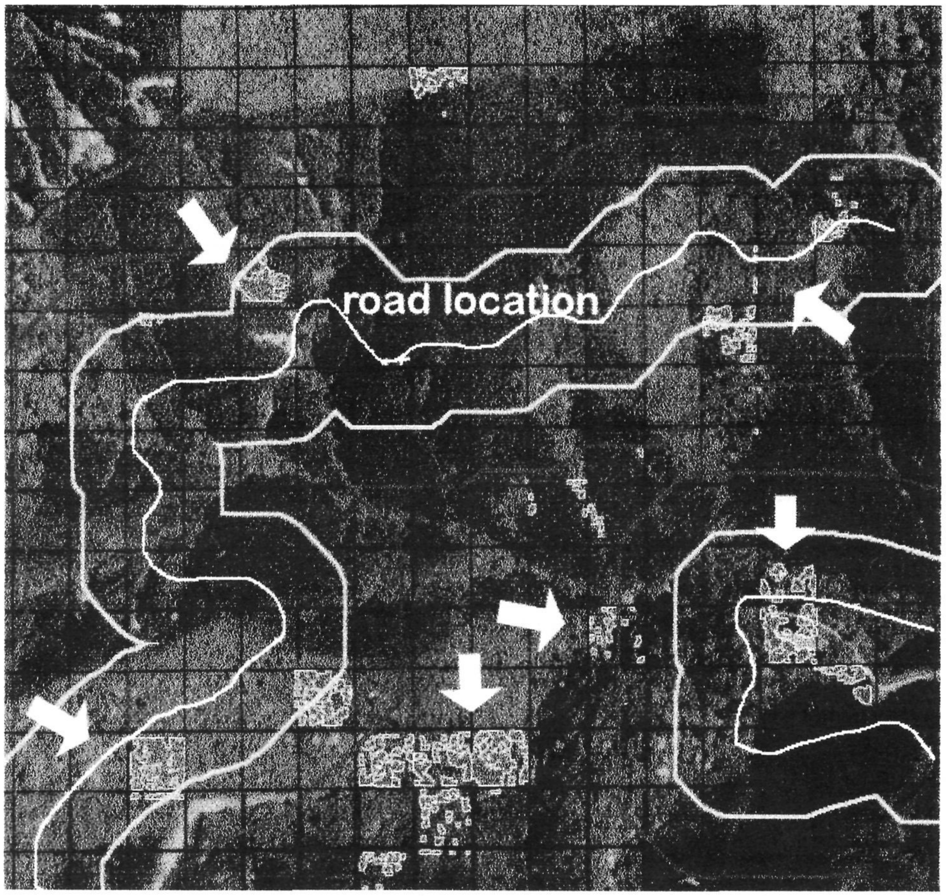


Figure10. Example of potential sensitive sites obtained from overlay analysis based on Boolean algebra: road location+50m linear buffer lines + slope class (80%<) + drainage area presence (1 ha) + natural forest.

A 25 x 25 m digital elevation model (DEM) created as a by-product of an orthophotograph was used for the TERDAS analysis. The manipulative key to linking together both the image and the TERDAS information/data was that the image was geometrically corrected to the National Grid and georeferenced with the DEM and route location data in a Photoshop imagery processing system. A considerable volume of computer output was generated by the overlay analysis and some of this is shown in the following Figures 7, 8, 9, 10 and 11.

This overlay analysis provides a photo map of some sensitive site components in terms of route selection at the full spatial resolution of the imagery and a link between the coarse resolution of the TERDAS information/data (a 25 x 25 m DEM) and the fine spatial resolution of the photo image. It allows the site investigation for route selection to drive the image classification with regard to the colour properties of the image and the potential impact attributes derived from TERDAS system.

CONCLUSION

In this age of satellite imagery, video cameras, and global positioning satellites, it is easy to overlook the advantages and uses of aerial photography as a source of spatial information. However, this may be a huge mistake. Aerial photography will continue to be an important source of spatial information for a long time to come. Any project that reviews changes over time must rely heavily on aerial photographs. Satellite imagery and other remotely sensed data are too new to be of much historical significance. In addition, only aerial photographs provide the accuracy, precision and detail required for many mapping projects.

Traditional procedures of photogrammetric data capture characterized by interdisciplinary or skill-enhancing methods, however, may be insufficient to address all of today's environmental issues which require detailed, site-specific, carefully time quantitative and qualitative spatial information. Digitizing the aerial photography/orthophotography and entering it into a computerized imagery processing system is comparatively more complicated than using the photo to directly interpret, but digital processing produces significantly more consistent results and the greater amount of spatial information inherent in the photo.

The digital imagery processing system appears to offer an improved way to indirectly measure and/or to interpret features from photographs using a pixel-based aggregation technique and discriminant function analysis. Further, the system, as well as a stereoplotter system [12], provides a direct way to input polygon data from image to a GIS. It can also be a source for one of the important GIS data layers.

The capabilities of aerial photography and image data processing systems are not basically *competitive* but *compensative*. Consequently, they are accountable for the accuracy of their interpretation, and correct and upgrade their results with field work and on-site verification.

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