Technical Report

Development of a digital orthophoto generation system for analysis of forest canopy dynamics

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We have developed a PC-based system that generates digital orthophotos for use in analysis of forest canopy dynamics. This system uses an aerial photograph, a Digital Surface Model (DSM), and a topographical map. The system's components are a PC, a scanner, the developed program, and image-processing software. The operation is simple, and the system is cost-effective and useful, although making the DSM is costly. The entire algorithm is written in the FORTRAN programming language for use in a PC environment. The resulting digital orthophotos, in image quality and accuracy, bear comparison with orthophotos generated by aerial survey companies.

Keywords : Aerial photograph, Digital orthophoto, Digital Surface Model, Historical analysis, PC-based generation system

Introduction

In contrast to satellite sensor data, aerial photographs of many areas have been available since the 1950s in Japan, which are high-spatial resolution. This airborne data is thus effective for use in the historical or temporal analysis of forest canopy dynamics. Aerial photographs are widely used in forest inventories, both to delineate stands and to aid fieldwork (Pitkanen 2001); they are also an important source of information for studies of vegetation dynamics (Dunn *et al.* 1990; Green *et al.* 1993).

Recently, there has been increasing interest in the use of digitized photographs for both strategic and operational levels of forest management. Analysis of digitized photographs are more rigorous and repeatable than analog aerial photographs, which made it possible to use the new range of techniques offered by Geographic Information Systems (GIS), (Gagnon *et al.* 1993). For example, research has been conducted into the potential for automated identification of the numbers of individual trees (Dralle and Rudemo 1996, 1997), modeling of tree density and change (Kovats 1997), yield estimates derived from two- and three-dimensional models of forests and their canopies (Dralle and Rudemo 1997), and forest condition (Holmgren *et al.* 1997). Such work aims to refine inventories and provide information that is required in the operational management of individual forests (Miller *et al.* 2000).

A digital orthophoto from a rectified aerial photograph can be combined with field survey data to compare historical changes. The generation of a digital orthophoto involves several stages, each of which has an associated cost. In the interests of efficiency, the acquisition of an orthophoto must be performed in a cost-effective manner (Spradley 1996). In the past, we have acquired digital orthophotos from an aerial survey company. However, this has proved costly and time-consuming, mainly due to personnel expenses. The orthophoto-generation software currently

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Table 1. Hard ware and Software configurations

Personal Computer	CPU: Pentium III 766MHz
	Memory: 256Mb
	Hard disk: 15Gb
	OS: MS-Windows98
Scanner	Canon color image scanner: 600dpi(A4-size)
The developed program	Written in Fortran programming language
Image-processing software	Adobe Photoshop 6.0, Adobe

available for desktop computer use (ERDAS Imagine, ERDAS) has been used in a number of studies (Fox *et al*. 2000; Miller *et al*. 2000), but the software is expensive and inflexible. Doytsher and Hall (1995) developed a program to generate digital orthophotos, and their system is designed to handle a considerably oblique photograph. Although the focal length and the flight altitude are basic information for generating a high-accuracy digital orthophoto, these factors were not used in their system.

In this study, we developed a PC-based system that generates digital orthophotos for use in analysis of forest canopy dynamics. Our system uses an aerial photograph, a digital surface model (DSM), and a topographical map. The system components are a PC, a scanner, the developed program, and image-processing software (Table 1). The entire algorithm is written in the FORTRAN programming language for use in a PC environment.

Using aerial photographs is indispensable for analyzing long-term and large-scale forest canopy dynamics (Fujita *et al*. 2003a, b; Nakashizuka *et al*. 1995; Tanaka and Nakashizuka 1997). Therefore, a low-cost system that generates digital orthophotos for use in analysis of forest canopy dynamics is much needed.

Materials and Methods

Study site

We used the Tatera Forest Reserve as a study site. The reserve is located at the center of the south island of Tsushima, at 34°25′ N and 129°20′ E, between the Japanese Archipelago and the Korean Peninsula.

This 100-ha reserve is situated on the north-facing slope of Mt. Tatera, 120 m to 560 m above sea level. The topography is flat or gently sloping at lower altitudes, and rather steep at higher altitudes. The well-developed broad-leaved evergreen forest is dominated by *Castanopsis cuspidata* and *Distylium racemosum* at lower altitudes, and by *Quercus acuta* at higher altitudes (Itow 1991). At lower altitudes, some canopy trees exceed 1m in diameter at breast height (dbh), and the height of the canopy is approximately 20-30 m. The reserve is a truly primeval, broad-leaved evergreen forest, and has been free from human disturbance for centuries.

A 4-ha (200 m × 200 m) permanent plot was set up within the reserve in 1990, and has been investigated and analyzed by individual tree surveys (Itow 1991; Manabe *et al*. 2000; Miura *et al*. 2001; Miura and Yamamoto 2003). Moreover, long-term dynamics of canopy states were analyzed using digital elevation models generated from historical aerial photographs (Fujita *et al*. 2003a, b). Fujita *et al*. (2003a, b) used only elevation data that obtained from aerial photographs. When vegetation data that obtained from orthophotos will be added to these data, more detailed forest dynamics will be analyzed. Therefore, this plot was suitable for our analysis.

Materials

The system that we developed uses an aerial photograph, a DSM, and a topographical map. The DSM and the topographical map are the index of the right position and height. The DSM is used to rectify distortion of geographical features, and the topographical map is used to rectify locational distortion. The aerial photograph and topographical map are digitized using a scanner, and the DSM and topographical map must have a unified coordinate system.

We used a natural color aerial photograph (1 : 8000 scale, 11 November 1998, Fig. 1) taken at an altitude of approximately 1400 m from a low-flying aircraft. This photograph was scanned at a high resolution to create an 8-bit color-scale image, at 406 dots per inch (dpi). At 406-dpi, each pixel of the scanned image represented approximately 0.5 m×0.5 m on the ground. In this resolution, tree crowns of the study area can be described enough. A topographical map (we used 1/25,000 scale map in this study) was scanned using 635-dpi resolution; each pixel of the scanned image represented approximately 0.1 m×0.1 m on the ground. In this resolution, a control point can be measured clearly in this map.

Elevations at the corners of every 2.5-m quadrat were digitized for a 10-ha area on the aerial photograph using a stereoplotter (AVIOLYT BC/LMT, Leica). Three photographs were used to obtain stereo-images covering the area. An aerial survey company (Chuoh Consultants, Nagoya, Japan) provided the elevation data. We interpolated the provided elevation data to 0.1-m quadrats by the bilinear transformation algorithm. The 2.5-m quadrat elevation data was used to analyze long-term dynamics of canopy states in the 4-ha plot. We used 0.1-m quadrat data in order to obtain higher spatial resolution images.

Measurements of coordinates

To determine coordinate transformation between the aerial photograph and the topographical map required measurement of the locations of several points on the digitized images, and several default values on the originals had to be identified (Fig. 2).

Orthorectification was performed on single aerial photograph and the plot was located in the center (Fig. 1). The location of the fiducial mark symbols at the four corners of the aerial photograph (Fig. 1), the focal length of the camera, and the flight altitude were identified as defaults. The locations of the fiducial marks and control points on the digitized aerial photograph were measured. Control points are points that are precisely in agreement on the aerial photograph and the topographical map. Although set up of many control point is very difficult in aerial photographs almost covered by tree crowns, eight control points have been selected somehow around the 4-ha plot. The coordinates of three corners of the topographical map were identified as defaults. These corners, the control points, and the projection center (the center of the aerial photograph) were measured on the digitized topographical map.

Image-processing software (Adobe PhotoShop 6.0, Adobe) was used to measure the coordinates on the digital images.

Algorithms

Three algorithms are used; the affine transformation, the basic formula of central perspective and inversion, and the bilinear transformation (American Society of Photogrammetry 1980). The affine transformation rectifies distortion that occurs during digitization. The coefficients are calculated by the least-squares method using the coordinates of the fiducial marks or the corners of the topographical map. The transformation of the coordinate system between the original and a digitized image is possible using the following equations:

$$PX = A0px + A1py + A2$$
$$PY = B0px + B1py + B2$$
$$px = C0PX + C1PY + C2$$
$$py = D0PX + D1PY + D2$$

where px and py are the coordinates on the original; PX and PY are the coordinates on the digitized image; and A0~D2 are coefficients.

The perspective relationship between an aerial photograph and a topographical map is given by using the basic formula of central perspective and inversion. The coordinates of the control points and the projection center on the digitized aerial photograph and the digitized topographical map are transformed into the coordinate system on the originals by the affine transformation. The elements of the rotation matrix are calculated by spatial resection using the control points, the projection center, and the focal length of the camera. The coordinate system transformation between an aerial photograph and a topographical map is possible using the following equations:

$$px = ck(R_1(X-X_0)+R_4(Y-Y_0)+R_7(Z-Z_0)) / (R_3(X-X_0)+R_6(Y-Y_0)+R_9(Z-Z_0))$$

$$py = ck(R_2(X-X_0)+R_5(Y-Y_0)+R_8(Z-Z_0)) / (R_3(X-X_0)+R_6(Y-Y_0)+R_9(Z-Z_0))$$

where X, Y, and Z are the coordinates on the map; px and py are the coordinates on the aerial photograph; X_0, Y_0, and Z_0 are the coordinates of the projection center; R_1~R_9 are elements of the rotation matrix; and ck is the focal length of the camera:

$$R_1 = \cos\varphi \cos\kappa$$
$$R_2 = -\cos\varphi \sin\kappa$$
$$R_3 = \sin\varphi$$
$$R_4 = \cos\omega \sin\kappa + \sin\omega \sin\varphi \cos\kappa$$
$$R_5 = \cos\omega \cos\kappa - \sin\omega \sin\varphi \sin\kappa$$
$$R_6 = -\sin\omega \cos\varphi$$
$$R_7 = \sin\omega \sin\kappa - \cos\omega \sin\varphi \cos\kappa$$
$$R_8 = \sin\omega \cos\kappa + \cos\omega \sin\varphi \sin\kappa$$
$$R_9 = \cos\omega \cos\varphi$$

where ω is the lateral tilt (the rotation about the x-axis); φ is the longitudinal tilt (the rotation about the y-axis); and κ is the swing (the rotation about the z-axis).

The coordinates of an intersection of the DSM are transformed into the coordinate system of the digitized aerial photograph by two of the above-mentioned equations, and the gray-scale value for the location of the intersections is interpolated and re-sampled with the bilinear transformation algorithm using the following equation:

$$g = (1-dr-dc+drdc)g_1 + (dr-drdc)g_2 + (dc - drdc)g_3 + drdcg_4$$

where g is the gray-scale value for an intersection of the DSM; g_1~g_4 are neighborhood pixels of g; and dc and dr are the distance from g to two sides.

Results and Discussion

Orthorectification is particularly important in mountainous terrain, as it makes possible an acceptable level of geometric accuracy and removes the spatial distortion that is associated with high topographic relief (Zomer *et al.* 2002). Our study area is the mountainous forest. Orthorectification cannot avoid in order to link with field survey data.

A resulting digital orthophoto is shown in Fig. 3; this took 20 minutes to calculate all of the processes, which is highly efficient for such a simple system (Table 1). Although it is necessary to add easy adjustment of brightness, contrast, etc. further, this digital orthophoto bears comparison with an orthophoto generated by an aerial survey company in the accuracy (Fig. 4). RMS error between these two images was 0.52 m. Since the plot had a flat geographical character, generated digital orthophoto might be high accuracy. When digital orthophotos are generated in the steep topography area, it will require paying attention to accuracy.

In all available systems, including the developed system, the accuracy of the orthophoto is determined by the accuracy of the measurements of the control points. However, it is generally difficult to measure an accurate location and elevation of control point on a topographical map. In addition, many points in areas where the topography is complicated cannot be photographed because of shade. These are the common problems in the case of generating a digital orthophoto oneself.

It is important that the system is useful and cost-effective. By using the system that we have developed, a digital orthophoto that has the required resolution can be obtained promptly, and at a lower cost than commercially available orthophotos, although making the DSM is costly. Generally, the spatial resolution of commercially available DSM in Japan is 50 m. If this data is used, orthorectification is cost effective. It will be enough to analyze a landscape level. However, this spatial resolution is too rough to analyze an individual tree level.

The canopy height profile method for identifying gaps from aerial photographs (Nakashizuka *et al.* 1995) is a very effective tool in analysis of canopy structure over large areas. Fujita *et al.* (2003b) applied the method to analyze historical changes in gaps in the 4-ha plot using elevation data obtained from aerial photographs. Moreover, forest dynamics has been analyzed based on field survey data since 1990 (Manabe *et al.* 2000; Miura *et al.* 2001; Miura and Yamamoto 2003). The data obtained from digital orthophotos can be combined with these results, making a more detailed historical and temporal analysis possible. As a result, an aspect of forest dynamics that has not heretofore been clear can be revealed.

The developed system in this study can be downloaded from the following web site: http://www.agr.nagoya-u.ac.jp/~seitai/.

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林冠動態解析のためのデジタルオルソフォト作成システムの開発

板谷明美・山本進一

デジタルオルソフォトを作成するPCベースのシステムを開発した。システム構成は，PC，スキャナ，開発したプログラム，そして画像処理ソフトウェアである。開発したプログラムの全アルゴリズムは，FORTRANプログラミング言語で記述した。資料は，航空写真，デジタル林冠面高(DSM)，そして地形図を用いる。高解像度のDSMを作成するためには費用がかかるが，簡易なシステムで，効率的にオルソフォトを作成できるという点で大変有効なシステムである。また，作成したオルソフォトの画質や精度は，写真測量会社によって作成されるオルソフォトと匹敵した。

キーワード：航空写真，デジタルオルソフォト，デジタル林冠面高，経年解析，PCベースシステム

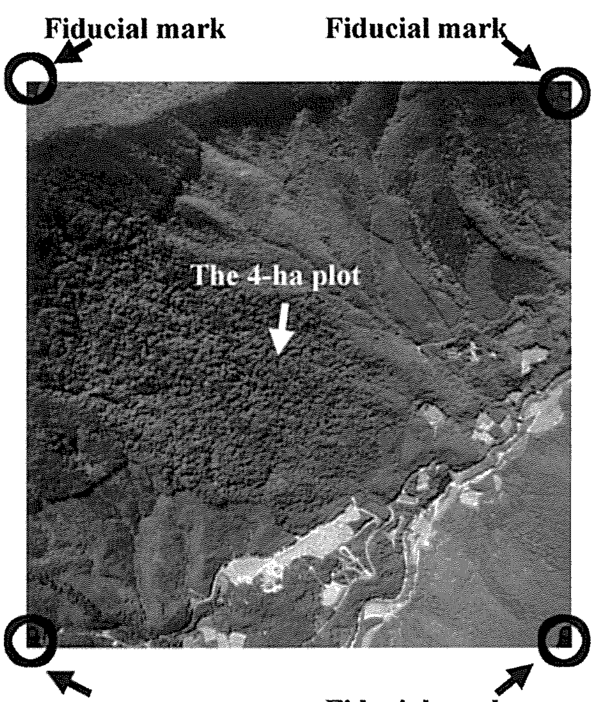

Fig. 1. A natural color aerial photograph of the Tatera Forest Reserve. This aerial photograph was transformed into a digital orthophoto. The 4-ha plot was included in a white frame. The plot is in the center of the white frame. Fiducial marks are in the four corners. The intersection of the diagonal lines between the fiducial marks is the projection center.

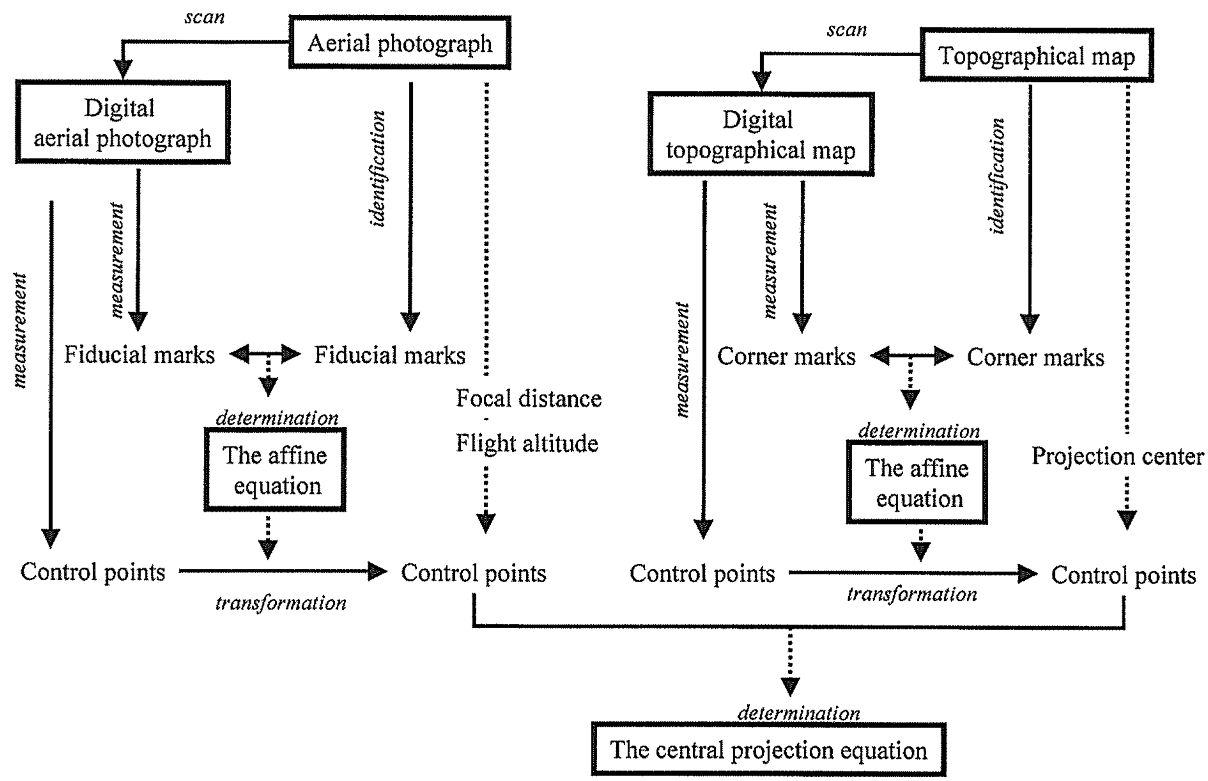

Fig. 2. Flow of the transformation for the coordinate system. The topographical map and the DSM are unified by the coordinate system.

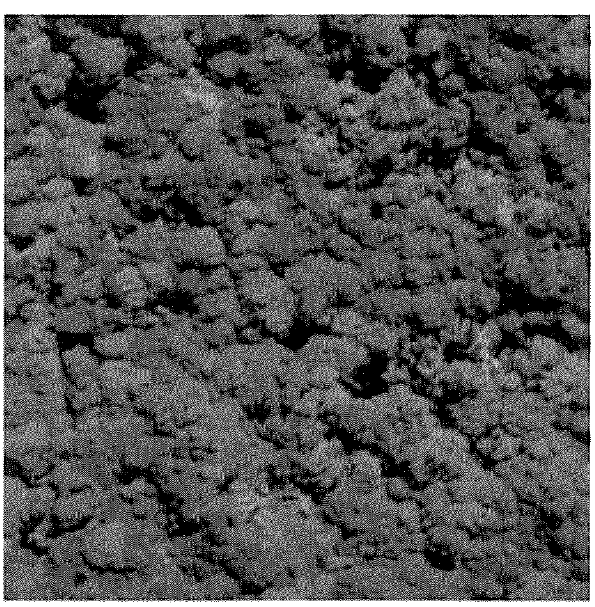

Fig. 3. A digital orthophoto of the 4-ha plot generated by the developed system.

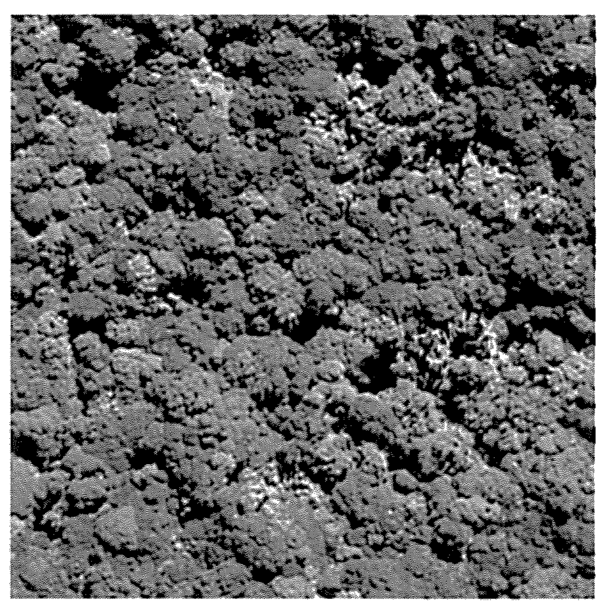

Fig. 4. A digital orthophoto of the 4-ha plot generated by an aerial survey company (Chuoh Consultants, Nagoya, Japan).