DSM BASED ORIENTATION TECHNIQUE FOR DIGITAL STEREO PHOTO IMAGES

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ABSTRACT

Digital Surface Model Based Orientation Technique is a new method for stereo image orientation based on image registration technique. The basic idea is that this orientation technique optimizes orientation parameters (, x, y, z) of each image of a stereo pair so as to give best image matching at each point on a digital surface model. This method does not require ground control points (GCP) but uses digital surface model instead. Experimental test resulted that the precision of orientation is better than the resolution of DSM.

1. INTRODUCTION

Aerial photo is one of the most important spacial data sources because of its reality and abundance of geographical information. However, users often encounter difficulties in utilization of them, since in most cases orientation parameters of photos are not available and users have to effort to find relationship between photos and other geographic or computer graphic object by themselves. To provide solution for such kind of needs, we have studied orientation method with existing geographic data such as digital maps and digital surface models (Doihara et.al.(1999)).

Here we propose a digital surface model (DSM) based orientation technique, which can calculate absolute orientation parameters automatically with DSM available. DSM based orientation goes ordinary photogrammetric process reversely. DSM based orientation conducts optimization of orientation parameters with existing DSM, whereas, in photogrammetry, operator first calculates orientation parameters for pairs of images and then calculate or measure surface model by triangulation. This method uses DSM instead of ground control points for orientation process.

Image registration technique is one of the important backbone of DSM based orientation. The most important difference from existing registration technique, such as Szeliski et.al (1994) or Oda (1998), is that our registration is performed on orthoimages: the algorithm optimizes orientation parameters which create approximately the same orthoimages from stereo pair images.

This paper first describes the theory of DSM based orientation, including basic strategy and implementation in least square method. After that we show some results of tests with this theory to show the performance and precision of this technique.

2. THEORY OF DSM BASED ORIENTATION

2.1 Basic Strategy

The basic idea of this method is to solve image registration problem under the condition that the position of objects in the stereo scene is known. With assumption of some proper initial value of absolute orientation parameters, image coordinates $p1$ and $p2$ on the stereo images I_1 and I_2 can be calculated for points on DSM. If the absolute orientation parameters are closer to the correct value, the difference between pixel values at $p1$ and $p2$ should become smaller. DSM based orientation calculates the parameters which give a least squares solution of the following evaluation function   :

$$ = I_1 p1 - I_2 p2 ^2 \tag{1}$$

where differences of pixel values between the stereo pair images are summed up.

2.2 Evaluation Function

Figure 1. Stereo Images and DSM

Suppose that we have digital surface model (DSM) $z = z(x, y)$, and that camera position $P = {}^t[X\ Y\ Z]$ and camera attitude $T = {}^t[\quad]$ are unknown. We use notation of full absolute orientation parameters of the camera as below.

$$E = {}^t[{}^t T\ {}^t P] = {}^t[\quad X\ Y\ Z] \tag{2}$$

Camera coordinates P_r of a point $p = {}^t[x\ y\ z(x, y)]$ on DSM can be described with P and T.

$$P_r(3= {}^t[x_r\ y_r\ z_r] = R(T)(p - P) \tag{ }$$

where $R(T)$ is the rotation matrix:

$$R(T) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & cos & -sin \\ 0 & sin & cos \end{bmatrix} \begin{bmatrix} cos & 0 & sin \\ 0 & 1 & 0 \\ -sin & 0 & cos \end{bmatrix} \begin{bmatrix} cos & -sin & 0 \\ sin & cos & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{4}$$

Equation (3) and (4) give image coordinates P_{pht} on which point on the DSM $(x, y, z(x, y))$ is projected:

$$P_{pht}(x, y, E) = {}^t[x_{pht}\ y_{pht}] = {}^t\left[-\frac{c x_r}{z_r}\ -\frac{c y_r}{z_r}\right] \tag{5}$$

where c is the focal length of the image.

An orthoimage $Iorth(x, y, E, I)$ can be composed from the image I with the following equation:

$$Iorth(x, y, E, I) = I(P_{pht}(x, y, E)) \tag{6}$$

For stereo pair images I_1 and I_2, two ortho images $Iorth_1$ and $Iorth_2$ can be computed by equation (6).

If absolute orientation parameters of I_1 and I_2 are closer to the correct value, difference of two ortho image $Iorth_1$ and $Iorth_2$ should be smaller at each point on DSM. DSM based orientation calculates the parameters which minimize the difference of two ortho images.

The difference of image values between $Iorth_1$ and $Iorth_2$ at $p = {}^t[x\ y\ z(x, y)]$ is:

$$e(x, y, \textbf{\textit{Eall}}, I_1, I_2) = Iorth_1(x, y, \textbf{\textit{E}}_1, I_1) - Iorth_2(x, y, \textbf{\textit{E}}_1, I_1) \tag{7}$$

where $\textbf{\textit{E}}_1$ and $\textbf{\textit{E}}_2$ are absolute orientation parameters of stereo image I_1 and I_2 :

$$\textbf{\textit{E}}_1 = {}^t\left[{}^t\textbf{\textit{T}}_1 \ {}^t\textbf{\textit{P}}_1\right] = {}^t\left[\omega_1 \ \varphi_1 \ \kappa_1 \ X_1 \ Y_1 \ Z_1\right] \qquad \textbf{\textit{E}}_2 = {}^t\left[{}^t\textbf{\textit{T}}_2 \ {}^t\textbf{\textit{P}}_2\right] = {}^t\left[\omega_2 \ \varphi_2 \ \kappa_2 \ X_2 \ Y_2 \ Z_2\right] \tag{8}$$

and $\textbf{\textit{Eall}} := {}^t\left[{}^t\textbf{\textit{E}}_1 \ {}^t\textbf{\textit{E}}_2\right]$

We can define evaluation function $Eall$ for least square optimization as below:

$$Eall = \sum_i^n e(x_i, y_i, Eall, I_1, I_2)^2 \tag{9}$$

where n is the number of points on DSM which are seen on both of the stereo images.

2.3 Least-Square Optimization

We have adopted Gauss-Newton method for non-linear least square optimization. This method revises target parameters $Eall$ with $\Delta Eall$:

$$Eall + \Delta Eall \rightarrow Eall \tag{10}$$

$\Delta Eall$ can be computed by the following equation:

$$\Delta Eall = -\left({}^tA \cdot A\right)^{-1} \cdot {}^tA \cdot e \tag{11}$$

where

$$e = {}^t\left[e_1 \ e_2 \ \cdots \ e_2\right] \tag{12}$$

$$A = {}^t\left[\frac{\partial {}^te_1}{\partial Eall} \ \frac{\partial {}^te_2}{\partial Eall} \ \cdots \ \frac{\partial {}^te_n}{\partial Eall}\right] \tag{13}$$

This computation is repeated until the evaluation function $Eall$ converges on the minimum value.

Partial derivative $\dfrac{\partial e_i}{\partial Eall}$ can be computed by following equation:

$$\frac{\partial e_i}{\partial Eall} = \left[\frac{\partial e_i}{\partial E_1} \ \frac{\partial e_i}{\partial E_2}\right] = \left[\frac{\partial I_1}{\partial P_{pht1}} \frac{\partial P_{pht1}}{\partial E_1} \ -\frac{\partial I_2}{\partial P_{pht2}} \frac{\partial P_{pht2}}{\partial E_2}\right] \tag{14}$$

where

$$\frac{\partial I_1}{\partial P_{pht1}} = \left[\frac{\partial I_1}{\partial x_{pht}} \ \frac{\partial I_1}{\partial y_{pht}}\right] \qquad \frac{\partial P_{pht1}}{\partial E_1} = \begin{bmatrix} \frac{\partial x_{pht1}}{\partial \omega_1} & \frac{\partial x_{pht1}}{\partial \varphi_1} & \frac{\partial x_{pht1}}{\partial \kappa_1} & \frac{\partial x_{pht1}}{\partial X_1} & \frac{\partial x_{pht1}}{\partial Y_1} & \frac{\partial x_{pht1}}{\partial Z_1} \\ \frac{\partial y_{pht1}}{\partial \omega_1} & \frac{\partial y_{pht1}}{\partial \varphi_1} & \frac{\partial y_{pht1}}{\partial \kappa_1} & \frac{\partial y_{pht1}}{\partial X_1} & \frac{\partial y_{pht1}}{\partial Y_1} & \frac{\partial y_{pht1}}{\partial Z_1} \end{bmatrix}$$

$$\frac{\partial I_2}{\partial P_{pht2}} = \left[\frac{\partial I_2}{\partial x_{pht}} \ \frac{\partial I_2}{\partial y_{pht}}\right] \qquad \frac{\partial P_{pht2}}{\partial E_2} = \begin{bmatrix} \frac{\partial x_{pht2}}{\partial \omega_2} & \frac{\partial x_{pht2}}{\partial \varphi_2} & \frac{\partial x_{pht2}}{\partial \kappa_2} & \frac{\partial x_{pht2}}{\partial X_2} & \frac{\partial x_{pht2}}{\partial Y_2} & \frac{\partial x_{pht2}}{\partial Z_2} \\ \frac{\partial y_{pht2}}{\partial \omega_2} & \frac{\partial y_{pht2}}{\partial \varphi_2} & \frac{\partial y_{pht2}}{\partial \kappa_2} & \frac{\partial y_{pht2}}{\partial X_2} & \frac{\partial y_{pht2}}{\partial Y_2} & \frac{\partial y_{pht2}}{\partial Z_2} \end{bmatrix} \tag{15}$$

$\frac{P_{pht1}}{E_1}$ and $\frac{P_{pht2}}{E_2}$ in equation (15) can be analytically determined with the equation (3) and (4). In digital image processing image values are given by pixel values I_{pix} P_{pix} P_{pht} . Thus $\frac{I_1}{P_{pht1}}$ and $\frac{I_2}{P_{pht2}}$ can be denoted by following equations:

$$\frac{I_1}{P_{pht1}} = \frac{I_{pix1}}{P_{pix1}} \frac{P_{pix1}}{P_{pht1}} \qquad \frac{I_2}{P_{pht2}} = \frac{I_{pix2}}{P_{pix2}} \frac{P_{pix2}}{P_{pht2}} \tag{16}$$

$\frac{I_{pix1}}{P_{pix1}}$ and $\frac{I_{pix2}}{P_{pix2}}$ correspond to differential images in column and row directions. $\frac{P_{pix1}}{P_{pht1}}$ and $\frac{P_{pix2}}{P_{pht2}}$ can be calculated from the relationship between P_{pix} and P_{pht}, which can be affine or projective transformation if optical distortion or film deformation is negligible.

2.4 Variation of Optimization under Restriction

2.4.1 Optimization under Epipolar Geometry: Suppose that Epipolar geometry between the two images are known, i.e., relative rotation matrix R_{rel} and direction vector ${}^t\begin{bmatrix} 1 & b_y & b_z \end{bmatrix}$ from the optical center of I_1 to the optical center I_2 are given. In this case the target parameters $Eall$ have 7 degrees of freedom which is:

$$Eall = {}^t\begin{bmatrix} {}^tE_1 & L \end{bmatrix} = {}^t\begin{bmatrix} T_1 & P_1 & L \end{bmatrix} = {}^t\begin{bmatrix} 1 & 1 & 1 & X_1 & Y_1 & Z_1 & L \end{bmatrix} \tag{17}$$

where L is a scale parameter. The absolute parameters $E_2 = {}^t\begin{bmatrix} {}^tT_2 & {}^tP_2 \end{bmatrix}$ can be derived from the following equations.

$$R\ T_2\ =\ R_{rel}^{-1}\ R\ T_1 \tag{18}$$

$$P_2 = L\ \ R\ T_1^{-1}\ {}^t\begin{bmatrix} 1 & b_y & b_z \end{bmatrix}\ + P_1 \tag{19}$$

Instead of equation (14), $\frac{e_i}{Eall}$ can be expressed as follows:

$$\frac{e}{Eall} = \begin{bmatrix} \frac{e}{E_1} & \frac{e}{L} \end{bmatrix} = \begin{bmatrix} \frac{I_1}{E_1} - \frac{I_2}{E_1} & -\frac{I_2}{L} \end{bmatrix} \tag{20}$$

where

$$\frac{I_1}{E_1} = \frac{I_1}{P_{pht1}} \frac{P_{pht1}}{E_1} \qquad \frac{I_2}{E_1} = \frac{I_2}{P_{pht2}} \frac{P_{pht2}}{E_2} \frac{E_2}{E_1} \qquad \frac{I_2}{L} = \frac{I_2}{P_{pht2}} \frac{P_{pht2}}{E_2} \frac{E_2}{L} \tag{21}$$

2.4.2 Optimization with fixed parameters: Suppose that ith element value of $Eall$ (E_i) have been fixed and other unknown parameters should be optimized under this condition. This problem can be solved simply by setting 0 to $\frac{e}{E_i}$ in Jacobian matrix. The element ${}^tA\ A_{ii}$ is also set to 1 in convenience, to avoid deterioration in rank of matrix ${}^tA\ A$ in the equation (11). This derives that $E_i = 0$ and optimization procedure does not renew the element E_i.

This situation can be applied to conditions with combination of any fixed parameters, for example, when absolute parameters of one image are known, or when two optical centers are measured by, for example, GPS. It is recommended to use any restriction to compute DSM based orientation since restriction brings robustness to the result.

3. TEST AND RESULTS

3.1 Test with aerial Photos of Mountainous Area

The algorithm has been tested with four aerial photos of Japan Alps area (Figure 2). The test consists of four stages. In the first stage, relative orientation parameters between the first pair of image were calculated by observing some matching point coordinates.Then DSM based orientation was done on the first pair with 7 degrees of freedom under epipolar geometry restriction. After that, the orientation parameters of the third image were optimized by performing the algorithm on the second pair with the parameters of the second image fixed. Similarly the parameters of the 4th image can be computed. Digital elevation model of Japan Alps mountain area published by Geographical Survey Institute (50m mesh) was used in this test.
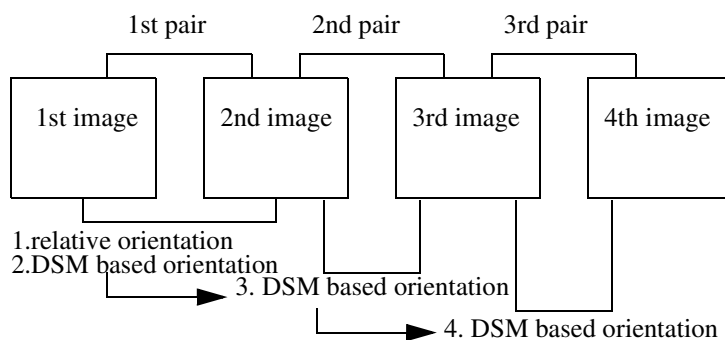
Figure 2. Flow of theTest

Figure 3 illustrates the process of the optimization of the third pair with 6 degrees of freedom. The second image row of the figure shows that difference of the two images is minimized through optimization. Figure 4 shows a mosaic image of orthophoto created with resultant orientation parameters and the DEM.
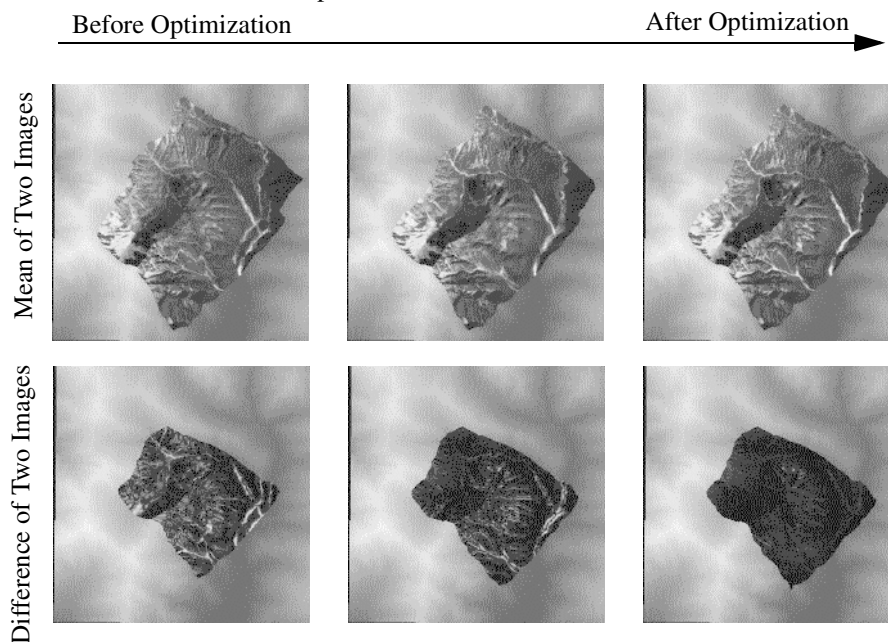

Figure 3. Optimization process of DSM Based Orientation

3.2 Precision of Orientation

The precision of the algorithm largely depends on resolution of DSM. Figure 5 shows the relationship between DSM and precision of orientation. Precision of the orientation is measured by computing mean GCP error at six GCP points. The tests resulted that the mean error is almost 1/2 or less than the resolution of DSM. This shows that precision of this method is better than resolution of original surface model.

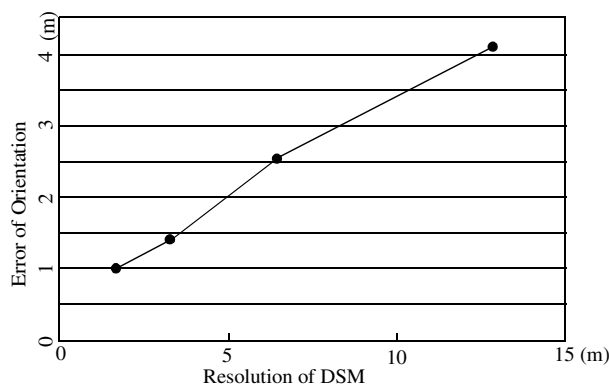**Figure 4. Mosaic Image of Mountainous Area (4 Photos)**

Figure 5. Relationship between Resolution of DSM and Precision of Orientation

4. CONCLUSION AND FUTURE WORKS

Digital surface model based orientation technique is useful if no GCP data and/or no orientation data are available. This technique can be applied to production of orthophotos or create textures for 3-D computer graphics model.

This method is especially suitable for photos of mountainous area. We are planning to implement this method in a system which create orthoimages and mosaic images through simple graphical user interface which can be operated by those who do not have knowledge about photogrammetry.

5. REFERENCE

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