INTERACTIVE RELATIVE ORIENTATION BETWEEN TERRESTRIAL IMAGES AND AIRBORNE LASER SCANNING DATA

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ABSTRACT:

This paper describes direct interactive relative orientation method between terrestrial digital images and laser scanner data. Traditionally, the orientation between images and 3D data requires interactive work and accurate reference points or visible features. Laser scanning data does not easily allow detection of breaklines or corner points. Due to the huge amount of data, however, it is possible with human intelligence and interactive orientation method to perceive the entity and to register terrestrial images and laser data to each other. The paper describes the basic tools for interactive orientation and contains discussion about the applicability of the method. An example from a test site is depicted in order to demonstrate interactive orientation in a practical situation.

1. INTRODUCTION

Airborne laser scanning technology has challenged the traditional measurements in urban and rural environments in Europe since 1996. Laser scanner survey provides a cloud of 3D points with accuracy almost equivalent to traditional land surveys. Laser scanning and photogrammetry can be seen as complementary methods. The laser is based on ranging and is quick airborne method to produce vertically oriented image data i.e. elevations. It works well in the areas that are difficult for stereoscopic photogrammetry. However, laser is sensitive to scanning corruption because of its geometric extrapolation, whereas photogrammetry is robust in its geometry.

The focus of the research in the field of laser scanning has moved rapidly from digital terrain models towards city models, extraction and modeling of buildings, segmentation and filtering, and integration of laser scanning data and digital images. Deficiencies of laser data include the lack of visual object information, limited geometric accuracy, the moderate resolution and the lack of redundancy needed for the quality control. Optical images can help to verify and fill these gaps. However, the integration or data fusion of these two data sets is in its early stages. The use of optical images together with airborne laser scanning is tackled mainly concerning aerial images. However, digital terrestrial images have been used with terrestrial laser scanning (Pfeffeir and Rottensteiner, 2001) in interiors modelling.

The other focus areas in laser scanning are the quality of laser scanning (Hyyppä and Hyyppä, 2003; Ahokas et al., 2002; Huising and Gomes Pereira, 1998), and the accuracy and the errors in laser scanning (Schenk, 2001; Burman, 2000). The high quality digital terrain models with regular grids or TIN are insufficient in the needs of accurate design or planning purposes. The knowledge over the precise position of breaklines is required (Brügelmann, 2000; Soininen, 2003).

Traditional photogrammetric methods to solve image orientation using 3D information are insufficient, because the extraction of accurate corner points or vectors from the laser scanning data is difficult. With interactive orientation, it is, however, possible to solve relative orientation, because human intelligence can easily fit the entity.

The aim of this paper is to present a novel algorithm for direct relative orientation between terrestrial close-range images and laser scanning data. The interactive orientation method is based on visual interpretation of laser scanning data superimposed on images. The ability of the method is verified with Real-Time Kinematic GPS observations. The paper also discusses about the potential of combined use of airborne laser data and terrestrial digital images based on panoramic mosaics.

2. MATERIAL

2.1 Panoramic Terrestrial Images

Composed digital panoramic images are useful for terrestrial photogrammetric measurements offering ultra-wide viewing angle and high image resolution. In order to create consistent panoramic images, the systematic lens distortions must be eliminated from the original images (Pöntinen, 2000).

Terrestrial images were chosen, because they offer improved complementary information to laser scanner data. Almost the same viewing direction of aerial images and airborne laser scanning can be advantageous for some purposes, but from terrestrial images it is feasible to visualize targets that are unreachable from both of these methods. In addition, terrestrial point of view gives an excellent opportunity to see, how laser altimetry behaves on the ground.

Two terrestrial panoramic images, establishing a stereo pair, were created from the Helsinki University of Technology (HUT) campus area in Otaniemi. The panoramic images, with the sizes of (9185 x 4939) (Figure 1) and (10729 x 5558) pixels, were composed both from 7 original images. The image capturing, in autumn 2002, was carried out using special panoramic platform for the digital camera (Figure 2) (Kukko, 2001; Pöntinen, 2002) making it possible to rotate the camera around its projection center. The camera used was Olympus C1400L, which was calibrated in HUT photogrammetric 3D test field. Details of creating panoramic images from concentric image sequences are presented e.g. in Haggrén et al. (1998) and Pöntinen (2000) and system calibration in Hartley (1994).

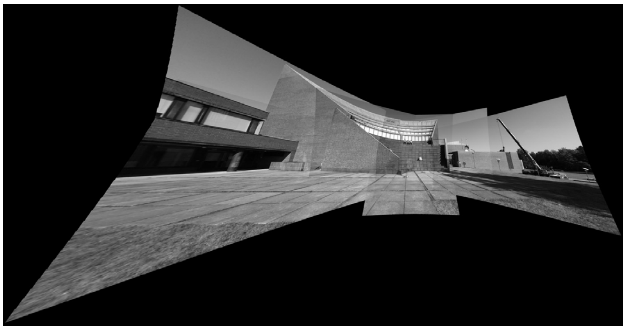

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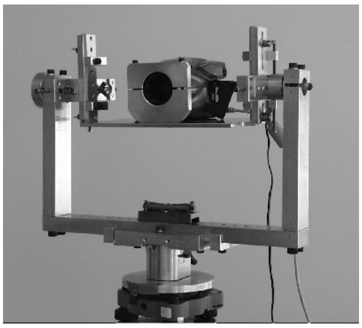
Figure 1. Terrestrial panoramic image, the size of (9185 x 4939) from Otaniemi test-area, is composed from 7 original images.



(© HUT / P. Pöntinen, A. Kukko)

Figure 2. HUT- camera rotation platform enables concentric imaging of the hemisphere.

2.2 Laser Scanning Acquisitions

Laser scanning campaign was carried out in August 2002 with TopEye and TopTerra in Otaniemi. The test site consists of 20 flight strips, ca 2.5 km in length. Otaniemi terrain can be characterized as flat and the size of the test site is approximately 2.5 km x 3.5 km. The TopEye data set is acquired from the altitude of 200 m resulting in average pulse rate between 2-5 points per m^2. The swath width was about 130 m.

The accuracy of digital elevation models (DEM) in Otaniemi and the accuracy of target models in Otaniemi were studied in Hyyppä and Hyyppä (2003). Height errors and accuracy of laser scanning in varying terrain conditions and differences in heights were calculated in Otaniemi area. The average vertical shift between reference data and laser data was 0.08 m, and the standard deviation of differences was about 0.05 m.

2.3 Ground Truth Data

Ground truth data from Otaniemi test site was collected with the Finnish Geodetic Institute. In order to be able to verify the accuracy of laser points in Otaniemi, coordinates of reference points were measured using Real-Time Kinematic (RTK) GPS receiver. Horizontal accuracy of the RTK was verified in Bilker and Kaartinen (2001) to be about 0.015 m and vertical accuracy 0.02 m. Altogether, over 1500 RTK-points were measured, 2/3 of them were ground points and 1/3 were trees, buildings, walls, lamps etc. The camera locations were also measured.

3. INTERACTIVE ORIENTATION METHOD

3.1 Rotating Image

For image orientation, the 3D-rotation matrix must be solved. In the case of interactive orientation, it is necessary to be able to control the elements of the rotation matrix in a sensible manner. A 3D-rotation matrix from the camera coordinate system to the ground coordinate system can be written

$$R = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix}, \qquad (1a)$$

which is usually explained with sequential rotations (omega, phi, kappa) around camera coordinate axes (x, y, z) when

$$\begin{aligned} r_{11} &= \cos\varphi\cos\kappa \\ r_{12} &= -\cos\varphi\sin\kappa \\ r_{13} &= \sin\varphi \\ r_{21} &= \cos\omega\sin\kappa + \sin\omega\sin\varphi\cos\kappa \\ r_{22} &= \cos\omega\cos\kappa - \sin\omega\sin\varphi\sin\kappa \\ r_{23} &= -\sin\omega\cos\varphi \\ r_{31} &= \sin\omega\sin\kappa - \cos\omega\sin\varphi\cos\kappa \\ r_{32} &= \sin\omega\cos\kappa + \cos\omega\sin\varphi\sin\kappa \\ r_{33} &= \cos\omega\cos\varphi \end{aligned} \qquad (1b)$$

or with azimuth, tilt and swing (Figure 3) when

$$\begin{aligned} r_{11} &= \cos\alpha\cos\kappa - \sin\alpha\cos\nu\sin\kappa \\ r_{12} &= -\cos\alpha\sin\kappa + \cos\alpha\cos\nu\cos\kappa \\ r_{13} &= \sin\alpha\sin\nu \\ r_{21} &= \sin\alpha\cos\kappa + \cos\alpha\cos\nu\sin\kappa \\ r_{22} &= -\sin\alpha\sin\kappa + \cos\alpha\cos\nu\cos\kappa \\ r_{23} &= -\cos\alpha\sin\nu \\ r_{31} &= \sin\nu\sin\kappa \\ r_{32} &= \sin\nu\cos\kappa \\ r_{33} &= \cos\nu \end{aligned} \qquad (1c)$$

All the rotations in equations 1b and 1c are defined to be positive to the clock-wise direction.

Being analogical to manual camera operations, azimuth, tilt and swing –system tends to be easier to understand and to predict its behaviour with terrestrial images.

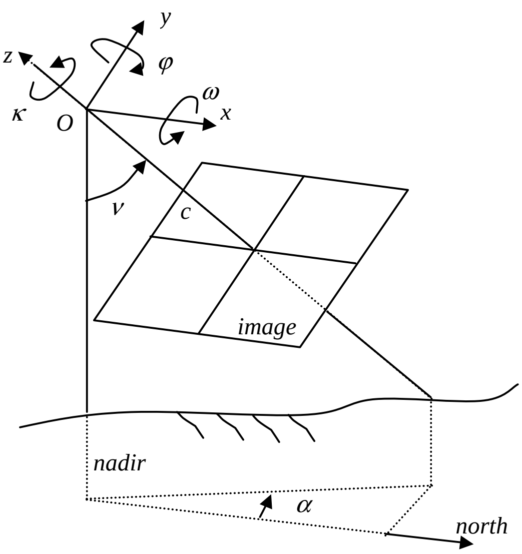


Figure 3. Typical rotations: around the axes of the camera coordinate system (ω, φ, κ) or azimuth, tilt and swing (α, ν, κ).

3.2 Shifts of Camera Location

Camera location must be found or known to solve interactively the correct 3D rotations of a camera. Shifts in the direction of either ground coordinate system axes or image coordinate system axes can be applied. Both methods have their own benefits. If the image plane is not parallel to either ground coordinate system axis, it might be difficult to predict how *X*- or *Y*-shifts effect to an image orientation. The Z-direction is easier to understand and to handle, however. If shifts along the camera coordinate system are used, it is easier to realize, how changes affect to the view. Shifts can be named: left, right, up, down, forward and backward (Figure 4). When a camera has tilt or swing, any movement affect to more than one ground coordinate directions. The directions of camera coordinate system axes can be found directly from a 3D rotation matrix. The first row of a 3D rotation matrix from a camera to the ground (eq. 1) is a unit vector projection of the viewing vector of the camera onto the *x*-axis of the camera, the second row is a unit vector projection of the viewing vector onto the *y*-axis and the third row is a unit vector projection of the viewing vector onto the *z*-axis. Shifts of the projection centre of the camera, or any 3D point (*X*, *Y*, *Z*) in ground coordinates, to the direction of the *x*-axis of the camera coordinate system can be written (Gruber, 2000)

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{shifted} = n\begin{bmatrix} r_{11} \\ r_{12} \\ r_{13} \end{bmatrix} + \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{original} . \tag{2}$$

Shifts, in ground coordinates, to the direction of the *y*-axis of the camera coordinate system can be written (Gruber, 2000)

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{shifted} = n\begin{bmatrix} r_{21} \\ r_{22} \\ r_{23} \end{bmatrix} + \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{original} . \tag{3}$$

Shifts, in ground coordinates, to the direction of the *z*-axis of the camera coordinate system can be written (Gruber, 2000)

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{shifted} = n\begin{bmatrix} r_{31} \\ r_{32} \\ r_{33} \end{bmatrix} + \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{original} . \tag{4}$$

The parameter *n* in equations 2, 3 and 4 defines amount of shifts. The coefficients ($r_{11} ... r_{33}$) are elements of 3D rotation matrix (eq. 1).

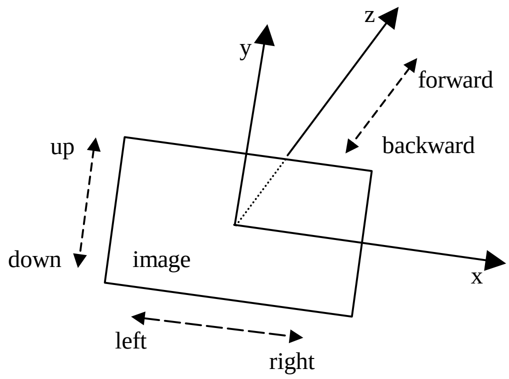


Figure 4. When shifts are made along camera coordinate axes, movements can be called: left, right, up, down, forward and backward.

3.3 Backprojection of Laser Scanning Data

When changes are applied to the rotations or to the location of the camera, the laser scanning data must be superimposed to the image with current orientation parameters in order to see the result. The backprojection of 3D point onto an image is calculated by the collinearity equations:

$$x = -c\frac{r_{11}(X - X_0) + r_{21}(Y - Y_0) + r_{31}(Z - Z_0)}{r_{13}(X - X_0) + r_{23}(Y - Y_0) + r_{33}(Z - Z_0)} ,$$
$$y = -c\frac{r_{12}(X - X_0) + r_{22}(Y - Y_0) + r_{32}(Z - Z_0)}{r_{13}(X - X_0) + r_{23}(Y - Y_0) + r_{33}(Z - Z_0)} \tag{5}$$

where *c* is a camera constant, a point (X_0, Y_0, Z_0) is the projection centre of a camera, (*X*, *Y*, *Z*) is a 3D ground point and terms ($r_{11} ... r_{33}$) are elements of 3D rotation matrix (see eq. 1). The origin of an image coordinate system is assumed to be at the principle point of an image.

3.4 Laser Data Selection

When an airborne laser scanning data is examined from a terrestrial point of view, it might be confusing to distinguish distances from backprojected laser data, because targets close and far from the camera are mixing together. A good approach to make side view easier to understand is to use color-coding by the distance (Forsman, 2001).

For an interactive relative orientation, there is no need to use all laser scanning data available. Only some clearly visible features from different sides of an image can be chosen to achieve a small set of data compared to the complete data. Backprojecting all the data onto an image can be quite time consuming. Using reduced set of laser scanning data interactive orientation becomes more sensible, because the visual respond of change of orientation parameters is faster.

4. RESULTS AND DISCUSSION

Two terrestrial panoramic images from the test area in Otaniemi were oriented interactively using a selected set of laser data. An overall image (Figure 5) exhibits, how the backprojected laser scanning data fits the first image after the interactive orientation. More detailed example from the same image is presented in Figure 6.

After the interactive orientation, the obtained camera locations were compared to the locations measured by RTK GPS (Table 1). Comparison reveals that the differences in heights between these two sources were minor. The result was as expected, since the imaging geometry is strong for this direction. Figure 7 shows how a 60 cm shift in camera height is clearly visible even from a constricted image.

Coordinate difference	Image 1 (m)	Image 2 (m)
ΔX_0	-0.215	-0.129
ΔY_0	-0.141	-0.078
ΔZ_0	0.012	-0.038

Table 1. Comparison between RTK reference measurements and interactively oriented camera locations.

Planimetric errors were bigger than height errors. This result was also expected from the imaging geometry. If the camera is moved forward or backward (see Figure 4) the effect on the image is much smaller compared to effects when moving left, right, up or down. The fine-tuning is enabled only if the viewing angle of the image is wide and the image resolution is high. These are the main reasons, why panoramic images are useful to achieve a higher planimetric accuracy.

One problem with test images used was that there were only planimetric features close to camera. This was not the best case for an interactive orientation. However, if the orientations were performed with the camera locations measured with RTK, it was not possible to fit exactly the laser points on the image. Therefore, there are probably some planimetric shifts between RTK and laser scanning data, and only part of planimetric errors can be explained with errors of interactive orientation.

Overall, the results were distinctly promising. Using the developed novel method, we can get good estimates of shifts between laser scanning data and required ground coordinate system. Instead of measuring dozens or hundreds of control points from the laser scanning area, it is possible to measure only the camera location and then make interactively relative orientation between an image and laser scanner data. Solving camera location with traditional exterior orientation of an image using ground control points is also possible, of course, if it is not easy to measure the camera location directly or if the correct orientation angles need to be solved as well.

The quality of interactive relative orientation depends mainly on the quality of laser scanning data. Furthermore, the orientation is the more robust the more there are samples per m^2 available. The pulse density on the ground is dependent on flying height, pulse rate, scanning method and if the flying strips are upon the each other.

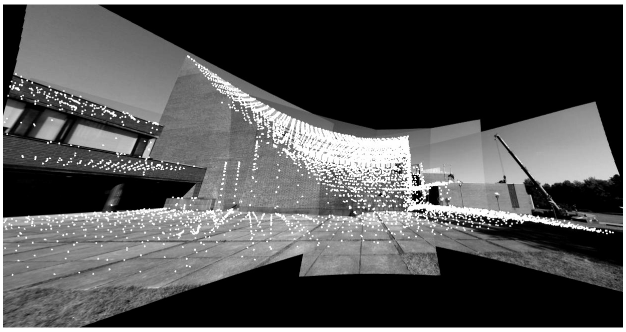


Figure 5. Overview of interactively oriented terrestrial panoramic image and back projected laser scanning data.

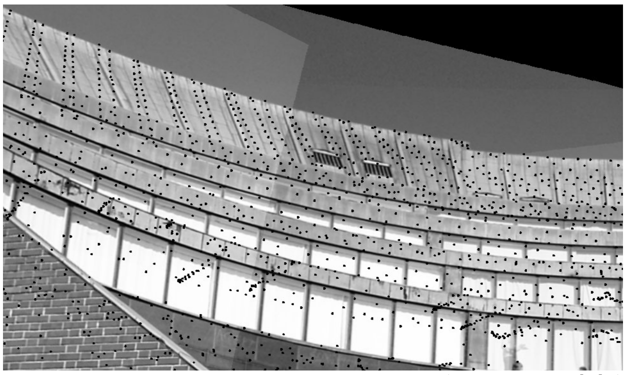


Figure 6. Resolution of panoramic image allows detailed views.

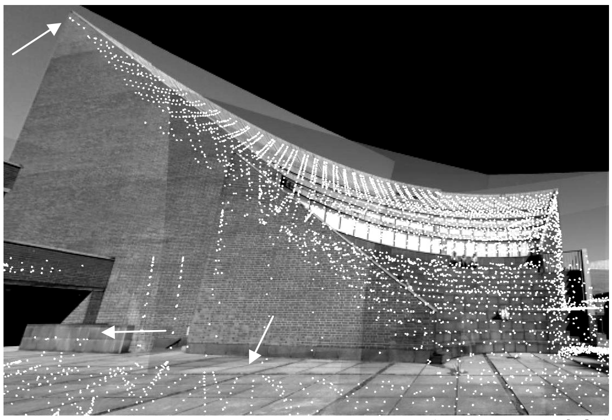


Figure 7. Shift of 60 cm in camera height is clearly visible from the image.

Experiences with test images raised some ideas, how to increase planimetric accuracy with good imaging planning. If two images with 90 degree viewing directions are used, the affect of the weaker geometrical conditions along the viewing direction of a camera is bypassed. In addition, if relatively oriented image pairs are used instead of single images, the method should be much more robust. With stereo image pair it is also possible to investigate the behavior of a laser scanning data in 3D.

Working with interactive orientation method requires proper tools. The biggest problem is that after any shifts to camera location the rotations must be changed before the final result of changes is clearly visible. This makes it more difficult to predict, how much the values should be changed at time. The use of an anchor point is a valuable tool to partially solve this problem. However, if a laser point is used as an anchor point, it is usually necessary to change it during the interactive orientation. In some cases, some pre-knowledge about the camera location or rotations is known and the interactive orientation method is fast and easy to handle. Table 2 accumulates some typical cases with interactive orientation method and describes the level of user friendliness. A rule of thumb with interactive orientation is that it is usually relatively fast and easy to find a coarse orientation, but the fine-tuning requires carefulness and takes longer time.

Properties:	Usefulness:
Shifts along ground coordinate system axes	Slow, difficult to handle
Shifts along image coordinate system axes	Faster, but still difficult to handle
Shifts along image coordinate system axes + anchor point(s)	Much faster, easier to handle
Known camera location	Fast and easy
Known camera rotations	Fast and easy

Table 1. Applicability of the interactive orientation method in different cases.

5. CONCLUSIONS

We have presented an interactive relative orientation method that is feasible for versatile applications. Since 1998 we have used this method with known 3D points, vector data, mobile imaging (Törönen et al., 2003), forested areas (Jokinen et al., 2003) and both terrestrial and airborne laser scanner data. With accurate vector data or 3D points, there are more efficient and accurate methods to solve image orientations, but interactive orientation can sometimes be faster and it deals robustly with data including several coarse errors. With laser scanning data the situation is totally different, because the data does not reveal easily accurate breaklines or corner points. However, the human intelligence is able to adjust this difficult data source quite easily with terrestrial images, if the scene contains enough identifiable features.

The accuracy of detecting differences in heights is high, if terrestrial images are used with airborne laser scanning data. The planimetric accuracy is not as good, because of the weaker imaging geometry. However, if several panoramic images with different viewing directions are used, also the planimetric accuracy can be adequate to many purposes.

With backprojecting a laser scanning data onto the oriented image it is easier to understand the behavior of laser scanning. In addition, relative orientation assists to verify quickly, if there are some internal errors, discontinues or gaps within laser data or if some changes have occurred in the target. Interactive relative orientation enables to operate without any control points or digital terrain model, if necessary. This could be advantageous in some areas, if it is difficult to get reference measurements.

Interactive orientation method is our first, easy and valuable step towards more sophisticated methods for relative orientation of airborne laser scanning data and terrestrial digital images. It is expected that combined use of laser scanning data and digital images will bring extra values to mapping and interpretation.

There has been some discussion whether laser scanning will displace the traditional photogrammetry. Both methods have some advantages and disadvantages and it would be gorgeous to use the best possible properties from both of them. We believe that combining these two methods will actually increase the use of the photogrammetry in the future. On the other hand, the laser scanning will also benefit from this progress.

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