ORTHOPROJECTION WITH CONTRAST EQUALIZATION USING TERRESTRIAL LASER SCANNING

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ABSTRACT:

The production time of true orthophotos become significantly shorter applying laser scanning. In this paper the comparison of laser scanning executed from moving vehicle and fixed station as well as the image capture is presented, together with some methods of orthophoto mosaicking and their results.
There is a fundamental difference between acquiring and matching point clouds of moving and fixed scanners. Hiding can be applied in scanning from fixed station and taking pictures from the same point. The position of the camera is not coincided with the origin of the scanned point cloud, which must be considered in the processing. It is advantageous that the outer orientation elements of the images can be determined automatically; furthermore several images can be captured from the same point with the same outer orientation. The color difference between the imagery of different stations can be reduced, if a series is taken from one position; therefore the post-processing becomes easier.
If the required full size orthoimage is defined previously with the necessary resolution, the geometric matching of the orthophoto pieces is not complicated. The positions of all stations as well as the orientation data of the taken pictures are automatically derived by the determination of the first scanner station in the coordinate system of the orthophoto, The color difference appearing in the mosaicking are to be adjusted by Erdas Imagine. The experiences are summarized and further methods are recommended to be tested.

Introduction

In the last decade the laserscanner became a widely used geodetic surveying equipment. Several research studies and investigations deal with the application area of the technology. Besides the engineering purposes, the application in human area continuously broadens. One segment is the architecture, surveying of monuments, registration, which can be based on digital true orthophoto.

Laserscanner Classification and Applications

The scanners are classified into 3 categories, such as airborne, terrestrial and object laserscanners. This paper discusses the potential of terrestrial laserscanners for orthophoto generation.
The most important advantage of laserscanning that the digital surface model of the surveyed area can be rapidly created with short pre-processing. This surface model serves as base for the orthophoto. In airborne surveying the true orthophoto has high importance, whereas the handling of the shadowed areas needs remarkable post-processing. Instead of the elevation model, the surface model is used also in terrestrial surveying; the problem of shadowed areas at the can be similarly solved. During terrestrial laserscanning the shadowed or hidden areas can be caused by columns, roof shoulders or trees int he foreground.

Terrestrial Laserscanning Methods

Two techniques of ground-based laserscanning are known. In the first case the scanner and the camera are continuously in motion by a transportation platform. The point measurements and registration is done in real-time, scanning the whole area is solved by moving the instrument. The location of points are computed similarly to airborne laserscanning. In general practice the scanner works in separate scan positions, the instrument does not move.
The Riegl LMS-Z420i scanner combined with a 6 Mpixel Nikon D-100 camera with known interior orientation elements and misalignment parameters were used in our investigations.
Remarkable time difference can be observed between the different scans, which causes light changes (e.g. brightness) in the environment. In digital photography, the features and parameters of the images can be manipulated which results in similar pictures.

Visibility Investigation, Eccentricity

In this scanner the offset between the scanner coordinate system and the camera is 25 cm, which has to be considered in creating the true orthophoto, since it can cause double projection. The problems caused by the offset can be seen at the edges. If the scanline is vertical, the problem is at the horizontal edges. By the way, the camera is not located in the vertical axis of the scanner, but it can be disregarded considering the minor impact on accuracy. The scanner is often not positioned vertically, since the desired field of view can be assured only this way. In this case the horizontal offset of the camera has to be considered and the above mentioned problem at the edges can be observed even at the vertical ones. The field of view of the camera depends on the focal length and surveying distance. The resulted image resolution often

much smaller than the angle-resolution of the scanner; it has to be taken into consideration in determining the orthophoto resolution. Increasing the surveying distance, the hidden areas (along with problematic areas of double projection) can be reduced, but also causes worse accuracy, which results in less reliable surface model and orthoimage.
Photos can be taken from any positions with known exterior orientation parameters, buti n this case the visibility has to be investigated.

Pre-processing

In order to reduce computation time, the point cloud has to cleaned, filtered and cropped to the investigated area. In case of facade surveying the points reflected from the neighboring environment (out of the investigated area) have to be deleted, the measurement noise and disconnected, isolated points have to be filtered and the unnecessary object points (vehicles, people, vegetation) have to be removed.
Surface model is generated based on the remained points; in the developed procedure the raster surface model has been chosen, since the software applying triangulated surface model created inadequate orthophotos about cylinders (e.g. columns), detailed objects (e.g. mosaics). As it can be seen in Figure 1, the image is fragmented, small details are lost. Applying raster surface model, the image is much nicer [Figure 2. a, b, c].

Figure 1. Whole orthophoto, b. Triangulated surface model c. Raster surface model

Another reason of applying the raster model is that it can be more easily created, mathematically simpler and is much closer to the data structure of the digital orthophoto. Due to the mathematic simplicity, several filtering, smoothening and correcting algorithms can be easily executed.

Processing

The computed data about the scan positions, the interior and exterior orientation parameters of each images can be accessed in the processing software (RiScan Pro) of the Riegl LMS-Z420i. Using these data orthophotos were created applying Matlab procedures.
First, the orthoimage plane has to be defined. In order to do that, new coordinate system has to be established, of which xy plane is the orthoimage plane, whilst the z axis points in the view angle. Each point coordinated of the applied point cloud have to be positive. Due to storage capacity reasons it is worth to apply a system with z coordinates with less digits. In our method, the vertical data is represented in 16 bits, which enables storing 65.535 values. In mm-level storing it allows 65.5 meter distance from the base plane. In case of longer distances, the highest value is registered which causes geometric distortion in the surface model. The investigated area can be reduced even in x or y direction, only the origo coordinates has to be fixes, as well as the resolution of the surface model, since (knowing the pixel-size) the width and height of the model determines the covered area.
If the camera offset is irrelevant, it is subservient to create surface models from point clouds of different scan positions; in this case the visibility-observation is also solved. In an area hidden from the camera no scanned point cloud can be found, since the scanner receives the beams emitted from the stationary point. If the offset is to be considered, the visibility analysis of the scan positions has to be executed to the combined point cloud.

Digital Surface Model Generation

During the post-processing a point list is generated from the point cloud transformed to the appropriate coordinate-system, which can be loaded by the developed software. Since the orthophotos are to be created by overlapping image segments with equal row and column numbers, this requirement is the same for the surface model. For that, the covered area and the orthophoto resolution has to be defined, i.e. the ground pixel size; first, the corner point coordinates of the orthoimage have to be given. If the bottom right corner is not the 0,0 coordinate point, it has to be fixed [Figure 2]. The coordinates of a pixel of the raster surface model in the orthophoto coordinate system are:

$$\begin{aligned} x_i &= t_x + p*(c-0.5) \\ y_i &= t_y + p*(\max_r - r + 0.5) \\ z_i &= f(r,c)/1000 \end{aligned} \qquad (1)$$

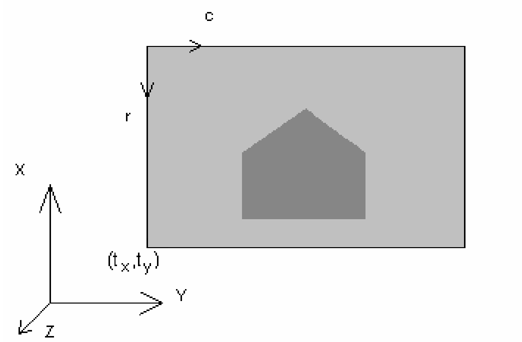


Figure 2. Connection between the pixel- and orthophoto coordinate system

Where:

x_i, y_i, z_i coordinates of a pixel of the surface model in the orthophoto coordinate system

t_x, t_y – Coordinates of the bottom left pixel of the surface model
p – pixel (real) size
max_r - number of rows of the surface model
r, c – image coordinate of a pixel (row, column)
f(r,c) – z height value in the surface model point with coordinates (r,c)

z_i value is the intensity of a pixel with given image coordinates (row, column), which is the surface distance from the xy plane in mm. Since all the other values are in m, conversion is needed.
In the surface model generation first the investigated area and the model resolution have to determined; the result is an empty matrix. Running through the point list, the location in the matrix has to be decided for each points: the z values of the points are loaded into the matrix. If there is an existing value in the particular grid, and the height difference is above the predefined threshold, the lower value is to be overwritten by the higher one. This threshold is aligned to the measurement accuracy of the points. For the applied scanner 20-30 mm threshold were used, since our experiences showed max. 10-15 mm point offset from the mean plane. If the particular height difference is below this threshold, the mean height value has to be computed; it increases the model accuracy. Difference above the threshold can be caused by the shape of the object, e.g. columns in front of the facade, or points reflected from walls behind open windows.
The point density of the laserscanning does not have to be equal to the orthophoto resolution. In this case, holes can be remained in the surface model, which can be eliminated by an algorithm running through the model. The algorithm computes a value based upon the neighboring values considering the possibility of edges next to the grid point; so can be used simple averaging techniques [Figure 3].

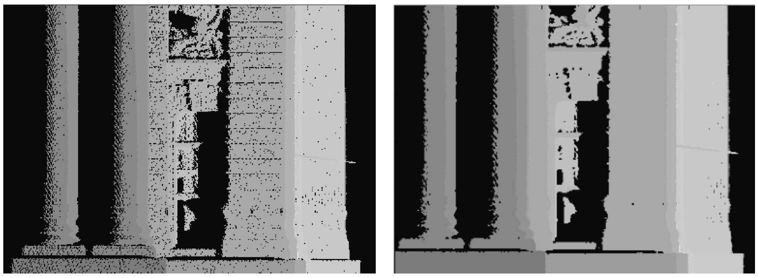


Figure 3. original and corrected raster surface model

If the density of the point cloud is lower than the orthophoto resolution, the model-resolution can be increased, especially in case of simple object-geometry. Extended plane surfaces can be represented by low-resolution scanning. In this case with the least possible changes of the geometry the model has to be refined (e.g. bilinear method).

Coordinate Systems

The camera position has to be defined in the orthophoto coordinate system; parameters can be gathered from RiScan. RiScan stores all the scan positions according to the first scan position (**SOP** matrix), which also contains the shift and rotation values. The mounting matrix is also stored by RiScan, which contains the transformation between the scanner and camera coordinate systems if the scanner is in the x direction. The back of the motionless part of the scanner defines the coordinate system of the particular scan position, but, since the camera is mounted on the rotating part of the scanner, for the exterior orientation the rotation matrix is required. The exterior orientation parameters of a single image are given by the following equation in scanpos 1:

$$v_{SP1} = \mathbf{SOP} * \mathbf{COP} * \mathbf{mount}^{-1} * v_{Photo} \qquad (2)$$

Where:
v_{Photo} - coordinates of the x,y,z unit vectors in the project coordinate system, and the origo coordinates in the camera coordinate system
v_{SP1} coordinates of the x,y,z unit vectors and the origo in the project coordinate system
SOP – The scanpos positions according to the project coordinate system registered by the first scanpos
COP – camera rotation in the scanpos coordinate system
mount – camera position in the scanner coordinate system at 0 deg rotation

The camera origo and unit vector coordinates in the project coordinate system are computed using v_{Photo} with (0,0,0,1) origo coordinates and x (1,0,0,1), y (0,1,0,1), and z (0,0,1,1) unit vector coordinates.
The orientation parameters of the first scanpos are required and sufficient for the exterior orientation of the images in the orthophoto coordinate system. Four points of the space have to marked, as the scanpos1 origo and the endpoint of the x y z unit vector. The orthophoto coordinate system definition can be done by matching procedure, e.g. determining the adjusting facade plane; the processing software transforms the points of the point cloud into the orthophoto system along with the marked points. The result is the coordinates of the 4 points in the orthophoto as well a sin the scanpos1 system. The transformation equation:

$$v_{ortho} = \mathbf{R} * v_{SP1} \qquad (3)$$

Since the vectors int he scanpos1 coordinate system contain only 0 and 1 values, the R rotation matrix is filled with the unit vector values given in the orthophoto coordinate system.

$$R = \begin{bmatrix} Xx & Xy & Xz & 0 \\ Yx & Yy & Yz & 0 \\ Zx & Zy & Zz & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (4)$$

Where:

X_x x component of the x unit vector in the orthophoto coordinate system,
X_y y component of the x unit vector in the orthophoto coordinate system,
etc.

The exterior orientation parameters can be computed with the following equation:

$$\mathbf{E=R*SOP*COP*mount^{-1}} \qquad (5)$$

$$E = \begin{bmatrix} R_{11} & R_{12} & R_{13} & T_x \\ R_{21} & R_{22} & R_{23} & T_y \\ R_{31} & R_{32} & R_{33} & T_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (6)$$

Where

$R_{11} \ldots R_{33}$ rotation coefficients
T_x, T_y, T_z shift

Orthophoto Generation
In the applied procedure each orthoimage segment is based on surface model sections of the same size. The result is orthoimages with remarkable size of black (with no information) areas. The advantage of it that in integrating more images only the pixels of the same area of the 2 or more images to be combined containing information have to be investigated and considered. If a pixel of any of the orthoimages is not black, then the particular intensity value has to be loaded into the integrated orthophoto. This is a rapid and easy to use algorithm which does not need interaction. If more images have information about the same area, then the users decides which image has to be considered by the software for the integrated orthophoto [Figure 4.a,b] The geometric content of the images does not cause any problems, since they are created by the surface model segments created with same requirements

Figure 4. a,b Ortophoto sections

Color Adjustment

Error sources: Since generally more images are needed to cover an object, sometimes the camera rotates about 180 degrees around the vertical axis of the scanner between the first and the last image. That is the reason that color differences can be found between the images taken from the same scan position depending on the environment. There are no differences in an orthophoto section but reasonable difference can be found between the two opposite sides of the covered area. Extended the orthophoto by images from different positions, the differences can be found in another sections; that is why choosing the image capturing time is so important. Otherwise the colors have to be adjusted, if possible with least human interaction, automatically.
Farther from the scan position the point density is lower as well as the information content of the photos. The surface model become sparser and the relevant image pixels cover too extended area of the surface or the beams intersect the surface with disadvantageous angles. These areas can be removed manually which increases the processing time [Figure 5.]

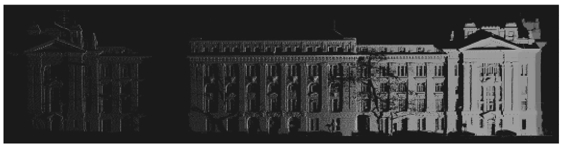


Figure 5. Completeness of the surface model is reducing farther from the scanner

Applied traditional softwares: From the commercial softwares, first the Erdas Imagine was tested int he investigations. Our experiences show that the applied color adjustment techniques did not provided sufficient results. One of the reasons that the orthoimage sections contain black areas causing problems for the averaging algorithms. Averaging image containing black areas with the complementary image results in green patches on the image [Figure 6]

Figure 6. Averaging color adjustment (Erdas Imagine)

After the test it has been stated that the software does not meet our demands.

In the next step the Erdas Model Maker was tested.

After the fine tuning the resulting arithmetic image has better quality, higher contrast and coherent colors [Figure 7]

Figure 7 Color adjustment with Model Maker

Since the result is good but did not meet our demands, we developed an own procedure.
The point of the first method is considering only the non-black pixel sin the overlapping area. Based on the overlapping sections, considering the size of the overlapping area and weighting by them, multipliers are computed for all the sections for all three color channels and the whole image was modified by these multipliers. The section parts will not have the same tone but the differences have been reduced. Iterating the same procedure the quality can be enhanced up to a certain point [Figure 8.]

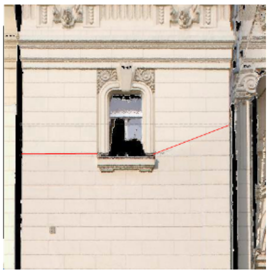
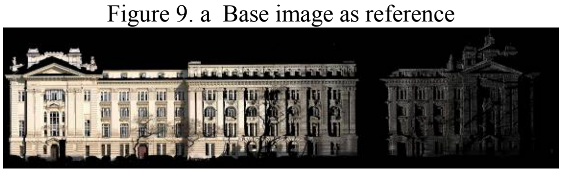


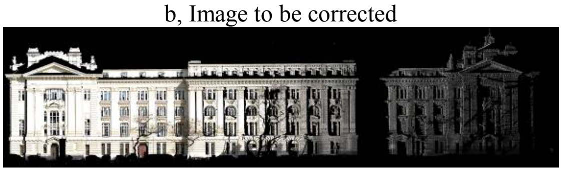
Figure 8. Iterative color adjustment with averaging weighted by the overlap (red line: matching line)

The point of our other method is choosing an image segment with appropriate colors and the other parts are to be adjusted to this section. First the section with the highest overlap (ont he base image) has to be selected. Averages by sections and color channels for the overlapping area have to be defined. The averages in the channels should be the same as it is in the base images. The differences of the averages of the different channels of the two images were added to the image to be modified and, independently, multipliers were generated from the average differences and used for the image correction. Figure 9 a,b,c,d shows the results.

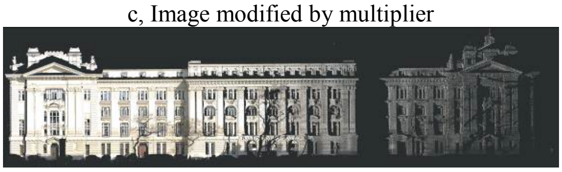
Figure 9. a Base image as reference



b, Image to be corrected



c, Image modified by multiplier



d, Image modified by addition

As it can be seen, the multiplier does not change the black areas and correctly modifies the color areas. In case of addition the black areas become brighter, which results in worse result. In case of these type of corrections the intensity value of a channel can reach the minimum/maximum value which causes information loss.

Conclusion

Imaging combined with laserscanning can be applied for creating true orthophotos. The measurement planning has to be executed depending on the desired end-product. The scan positions, number of them, the applied objective and the measurement resolution has significant influence on the resolution and quality of the orthoimage. The object-sensor distance has remarkable effect on point density and on covered area. The inappropriate areas have to be removed manually which increases processing time, as well as the manual cleaning (e.g. unnecessary surveyed objects) and corrections.

It can be concluded that the results are not perfect but show much better results as the tested softwares. Furthermore, it is important to note that the described procedure is not time-consuming; compared to the widely applied methods the same quality can be reached with less work.

Our goal in the future is to reduce the number of manual interactions without decrease in quality.

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