CREATING ORTHOPHOTO MOSAICS BY DIFFERENT PRINCIPLES OF AERIAL TRIANGULATION AND ITS GEOMETRICAL QUALITY

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Abstract: Consider, that in last century in technique and in technology in photogrammetry field big changes have taken place, it is good to know which one is better to use. One of the most significant parts of photogrammetry is making high-quality orthophoto mosaics. One of the important indicators of orthophoto mosaics is its geometrical quality which is affected by the accuracy of passing various steps in making orthophoto mosaics, such as aerial triangulation. If a photo is captured by a matrix sensor, it has two or three overlapping areas; in addition, the particular importance of the ground control points located in those areas for the accuracy of triangulation should not be overlooked. Generally, three overlapping areas are used for locating these points, but in specific cases, this does not work, and we have to use points located in two overlapping areas (e.g. areas covered by forest or water). In that case, it is necessary to know how it affects the accuracy of the whole aerial triangulation, the further processing of photos or the final product itself. The aim of the present research work is to investigate the geometrical quality of an orthophoto mosaic, using for that purpose two mosaics of the same area, made according to different principles of external aerial triangulation. This is the major aim of the present paper, mainly due to the fact that the authors are not aware of any previous research of the kind.

Keywords: aerial triangulation, external aerial triangulation, geometrical quality, orientation, orientation parameters

1. Introduction
One of the most significant parts of photogrammetry is high-quality digital orthophotomosaics. For the producers of digital orthophotos, important conditions have been set, such as get fast and high-quality products. For this purpose, different digital opportunities and program software have been worked out, the usage of which mainly depends on the condition specified to the final product or to the quality conditions. As regards products of high-quality, such as orthophotos, it is important to know which of the factors mainly affect their quality. Such knowledge can spare time and avoid excessive work. Geometrical quality is one of the main indicators of orthophoto quality, depending in turn on the accuracy of input data and on the accuracy of passing different stages of making orthophotos, such as aerial triangulation, digital terrain model and mosaicing. The present research analyses one of the previously stated factors – aerial triangulation, videlicet external orientation of aerial triangulation, its effect on the whole process of triangulation, on the further processing and geometrical quality of orthophoto.

The focus of the research is on the covering area of aerial photos, where it is complicated to find and measure the necessary ground control points (e.g. areas covered by forest or water). Generally, the ground control points for the aerial triangulation should be located in three overlapping areas, but if it is complicated (like in the areas mentioned before) and we can use for ground control points only two overlapping areas, then it is essential to realize the effect on further processing of the photo and on the quality of final product.

For the study of external aerial triangulation accuracy, two different projects were set up with the same area and according to different principles of aerial triangulation. For the investigation of geometrical quality of orthophotomosaic, two orthophoto mosaics were made for both projects, in which ground control points on the mosaic were measured and compared with coordinates measured by GPS on the ground. Photogrammetric software PHOTOMOD was used for the research. This software is produced in Russia and is currently used in more than 50 countries. The software enables orthophotograph creation from the initial photographed image to the end product, using different modules - PHOTOMOD AT, Solver, DTM and Mosaic. PHOTOMOD system enables the processing of both analogue and digital aerial photographs. (Racurs 2010)

2. Materials and methodology
The main aims of the research were to investigate the effect of different principles of external aerial triangulation on the whole process of aerial triangulation, on further processing, and on the
geometrical quality of the final product. The research was split into two parts, accrued from the aims of the research:

1. the effect of different principles of external aerial triangulation on the whole process of aerial triangulation;
2. the effect of different principles of external aerial triangulation on the geometrical quality of orthophoto mosaic.

Locations of ground control points on the different overlapping areas of aerial photos were used to investigate the effect of different principles of external aerial triangulation on the whole process of aerial triangulation. For this purpose, two projects were set up with the software PHOTOMOD, one with ground control points located only in two overlapping areas (henceforth, the first project) and the other with ground control points located only in three overlapping areas (henceforth, the second project). There were 12 analogue aerial photographs in central projection, of the City of Tartu for both projects. Aerial photographs were organized in 4 strips, each strip containing 6 photos. The photographs were captured by a low flying aircraft (1532 m, focal length 153,190 mm) by a Swiss company on October 2, 2000; RC 20 camera, the optical type of camera 15/4 UAGA-P, with the aperture of 4,0 were used and the photographs were scanned with DSW200 scanner.

6 ground control points were used in both projects. Points were measured with Real Time GPS in summer 2009.

In order to investigate the effect of different principles of external aerial triangulation on the geometrical quality of orthophoto mosaic, the software PHOTOMOD was used for making mosaics on scale 1:2000 for both projects. Geometrical quality was investigated by 8 ground control points with Root Mean Square Error (RMSE). Coordinates of ground control points were measured on the mosaic and with GPS on the ground outside, being the same for both projects. For accuracy calculations, the GPS coordinates were considered true.

2.1. Aerial Triangulation (AT), Block Adjustment (Solver) and Block Processing

There exist two different successive modules in PHOTOMOD system for aerial triangulation: AT (Aerial Triangulation) and Solver (Block Adjustment) modules. AT includes defining interior orientation, external orientation and relative orientation. The interior orientation procedure determined the position and the orientation of the film coordinate system relative to the coordinate system of the digital image in both projects. Besides, during interior orientation, the parameters describing a systematic film distortion were found. The parameters defined in the process of interior orientation were used to transform the measured image point coordinates from the digital image coordinate system to the film coordinate system. Five types of transformation from the digital image coordinate system to the film coordinate system are implemented in the PHOTOMOD AT module.

In the process of interior orientation, coordinates of fiducial marks were measured. Transformation of fiducial marks depends on the initial fiducial marks of the selected data (at inserting camera data). Affine transformation was selected.

Relative orientation included addition of tie points into the overlapping areas between strips and adjacent images, at least 6 points in each.

For external orientation, various 6 coordinates \((x, y, z)\) of ground control points were determined in L-Est’97 coordinate system for both projects, according to the principles described before. After the input of the points to the corresponding catalogue, their location was determined on the photos. This is one of the main aspects defining orthophoto mosaic quality. The location of the point should be cognitive in the photo, therefore, the sketches from the point location in nature, are exceptionally useful. You cannot use road crossings or axes for ground control point locations; because they are not reliable enough, especially if the photos and point measurements were made some time ago.

The ground control points were selected over the whole area for both projects and they were located in cognitive places like corners of parking grounds or corners of curbstones of roads (Figure 1).
Ground control points locations for both projects in L-Est'97 coordinate system are shown in figure 2.

After block adjustment, exterior orientation parameters for each photograph (alpha, omega, and kappa) were computed, as well as ground control points’ differences and tie points’ differences, which had to be smaller than 1 pixel in size (0.2m). The result was a block of imagery in geodetic coordinated system. Block adjustment for both projects was made by applying different methods. The first one is independent strips model method. This method is basically used to eliminate the gross errors, such as wrong control points coordinate values, incorrect tie point’s measurements, etc. The second method is independent stereo-pair method. This method is used to improve the accuracy, achieved by independent strips method. (Киселева 2009) For the analysis, only the second method was used.

For the investigation of the geometrical quality, mosaics were made for both projects. For mosaics of both projects, the 3D terrain model for each stereo pair was applied, using the toolset TIN (Triangulated Irregular Network). (DTM 2005)

For creating and editing TIN (TIN - vector model covering modeling surface with spatial elementary triangles), Delaunay algorithm was used. (Triangulated Irregular Network 2005)

Delaunay triangulation is a proximal method that conforms to the requirement that a circle drawn through three nodes of a triangle will contain no other node (Figure 3).
Delaunay triangulation has several advantages over other triangulation methods:

- the triangles are as equiangular as possible, thus reducing potential numerical precision problems created by long skinny triangles;
- ensures that any point on the surface is as close as to the node as possible;
- the triangulation is independent of the sequence in which the points are processed.

The most frequently used TIN type is the Adaptive model recommended to process large homogeneous or smooth images as well as those depicting water areas. The Adaptive model was created by calculating TIN nodes coordinates (nodes in the grid) automatically by the correlator. This TIN type was used in the present work. As a result, in both projects we got DTM (Digital Terrain Model) (Figure 4).

2.2 Analysis

The effect of different principles of external aerial triangulation on the whole process of aerial triangulation is shown by ground control point differences and by root mean square errors (RMSE) in Table 1 for the first project and in Table 2 for the second project. In tables X, Y, Z – are coordinates, calculated from the model; Xg, Yg, Zg – ground control point’s coordinates.
Table 1. Coordinate differences of ground control points and RMSE for the first project

<table>
<thead>
<tr>
<th>N</th>
<th>X-Xg (m)</th>
<th>Y-Yg (m)</th>
<th>Z-Zg (m)</th>
<th>Exy (m)</th>
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</thead>
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<tr>
<td>10B</td>
<td>-0.200</td>
<td>0.122</td>
<td>0.120</td>
<td>0.234*</td>
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<tr>
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<tr>
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<td>-0.017</td>
<td>-0.010</td>
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</tr>
<tr>
<td>3</td>
<td>0.390*</td>
<td>-0.139</td>
<td>-0.128</td>
<td>0.414*</td>
</tr>
<tr>
<td>4F</td>
<td>0.084</td>
<td>-0.091</td>
<td>0.047</td>
<td>0.124</td>
</tr>
<tr>
<td>7B</td>
<td>-0.033</td>
<td>-0.033</td>
<td>0.102</td>
<td>0.047</td>
</tr>
</tbody>
</table>

mean absolute: 0.146 0.082 0.094 0.172
RMS: 0.190 0.093 0.106 0.211*
max: 0.390* 0.130 0.156 0.414*

Assuming that all the coordinates differences are supposed to be smaller than 1 pixel in size (0.2 m), we can see (marked *) that differences and RMSE of two points are bigger (p 10 B – 0.234 m and p3 0.414 m).

Table 2. Coordinate differences of ground control points and RMSE for the second project

<table>
<thead>
<tr>
<th>N</th>
<th>X-Xg (m)</th>
<th>Y-Yg (m)</th>
<th>Z-Zg (m)</th>
<th>Exy (m)</th>
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<tbody>
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<td>0.038</td>
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</tr>
<tr>
<td>15B</td>
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<tr>
<td>18</td>
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<td>-0.058</td>
<td>-0.085</td>
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</tr>
<tr>
<td>3A</td>
<td>0.070</td>
<td>0.081</td>
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<tr>
<td>6</td>
<td>-0.024</td>
<td>-0.000</td>
<td>0.088</td>
<td>0.024</td>
</tr>
</tbody>
</table>

mean absolute: 0.042 0.052 0.057 0.071
RMS: 0.047 0.061 0.062 0.077
max: 0.070 0.081 0.088 0.107

We can see from the results of the second project, that all points’ coordinates’ differences were in permitted dimension, it means smaller than one pixel in size.

Comparing both projects, we can conclude that the selection of ground control points in three overlapping areas improves the accuracy. Consider that if both points in two overlapping areas with differences and RMSE bigger then the permitted dimension are located on the first strip, it can affect the whole aerial triangulation and also the geometrical quality of the orthophoto mosaic. Geometrical quality of orthophoto mosaic was investigated for both project mosaics separately and then compared with each other. For investigation, 8 ground control points all over the orthophoto mosaic were used. Root mean square error \( (m) \) computed from Gauss’s formula (1) was the indicator for quality. Accuracy of root mean square error \( (m_m) \) was computed from formula (2). (Randjärv 2006)

\[
m = \pm \sqrt{\frac{\Delta^2}{n}} \tag{1}
\]

where \( \Delta \) - coordinate differences between points measured interactively and outside;

\( n \) – number of measurements.

\[
m_m = \pm \frac{m}{\sqrt{2n}} \tag{2}
\]

(Randjärv 2006)
RMSE was supposed to be smaller than 2.5 pixel size of aerial photo: 0.5 meters. Calculation of geometrical quality and RMSE of the first project are presented in Table 3. Calculations of the geometrical quality and RMSE of the second project are presented in Table 4.

### Table 3. Calculations of the geometrical quality of the first project (units in meters)

<table>
<thead>
<tr>
<th>Point no.</th>
<th>X</th>
<th>Y</th>
<th>X</th>
<th>Y</th>
<th>ΔX</th>
<th>ΔY</th>
<th>ΔX²</th>
<th>ΔY²</th>
<th>ΔX+ΔY²</th>
<th>Sum</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>Direction</th>
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<td>0,454</td>
<td>0,714</td>
<td>0,48</td>
<td>NE</td>
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<tr>
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<td>644262,187</td>
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<td>0,327</td>
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<td>0,019</td>
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</tr>
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</table>

### Table 4. Calculations of the geometrical quality of the second project (units in meters)

<table>
<thead>
<tr>
<th>Point no.</th>
<th>X</th>
<th>Y</th>
<th>X</th>
<th>Y</th>
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</tbody>
</table>

From the results of the first project we can see that RMSE in the X-axis is in the permitted size, but RMSE in the Y-axis is noticeably bigger. The RMSE of the whole mosaic is bigger then the permitted size as well – 1,325m.

RMSE of the orthophoto mosaic of the second project is in the permitted size – 0.386m.

In figure 5 is shown the affect of external orientation to the geometrical quality of whole mosaic using dislocations of both projects.
3. Summary and Conclusions

The quality of orthophoto mosaic can be evaluated by visual, geometrical and other qualities, which in turn are affected by various factors. Geometrical quality is at most affected by aerial triangulation and DTM. Aerial triangulation comprises internal, relative, and external orientation. External orientation can be acquired by two different principles. Differences between principles can be seen in the location of ground control points in overlapping areas on aerial photos. The present research work investigates the geometrical quality of orthophoto mosaic and one of the quality influencing factors – the external orientation in aerial triangulation, how it affects the accuracy of the whole aerial triangulation, further block processing and geometrical quality of the orthophoto mosaic.

There were two different projects used for the research work. Overall triangulation was made for both projects. However, ground control points located in only two overlapping areas were used for the first project and those located in three overlapping areas were used for the second one. For the investigation of effect orientation, orthophoto mosaics for both projects were made. Geometrical quality for the mosaics of both projects was analyzed and compared.

In order to analyze the effect of external orientation on the whole aerial triangulation, reports of aerial triangulations were used in which differences of ground control point coordinates and root mean square error were compared. The photos of 0.2 meters of pixel size were used for the project. This size was also the basis for calculating triangulation accuracy. The results of two projects compared, it can be seen that two points out of six in two overlapping areas were larger than required. The root mean square error of point 10 B – 0.234 meters and of point 3 - 0.414 meters. All points were of permitted size in three overlapping areas.

In order to analyze the effect of external orientation on the geometrical quality of orthophoto mosaic, coordinates of 8 ground control points were measured in both project mosaics and then compared with GPS coordinates measured outside. Root mean square error (RMSE) was taken as indicator for quality and was supposed to be smaller than 2,5 pixel size of aerial photo: 0.5 meters. While comparing calculations of geometrical quality of mosaics of both projects and then RMSE of both mosaics with permitted size, it came out that orthophoto mosaic made by ground control points located in three overlapping areas for the external orientation of aerial triangulation is more accurate then orthophoto mosaic made by ground control points located in two overlapping areas for the external orientation of aerial triangulation. The RMSEs of both projects were 0.386 and 1.325 meters, respectively. In conclusion, assuming that the principles of aerial triangulation with all ground control points depending on each other for the block adjustment are used, it affects the accuracy of final block, aerial

Figure 5. Dislocations of first project (a); dislocations of second project (b). (sizes of dislocations illustrative)
triangulation and the orthophoto mosaic. Consequently, it is better for aerial triangulation to select ground control points in three overlapping areas.

References:

Резюме:
НАТАЛЬЯ ЛИБА, ИНА ЯРВЕ. СОЗДАНИЕ ОРТОФОТОМОЗАКИ ИСПОЛЬЗУЯ РАЗЛИЧНЫЕ ПРИНЦИПЫ ТРИАНГУЛЯЦИИ И ИХ ТОЧНОСТЬ.

В последние десятилетия можно отметить большие позитивные изменения во всех областях фотограмметрии в том числе техники и технологии. Одним из важнейших направлений в области фотограмметрии является создание качественного цифрового ортогофо и в частности цифровой ортофотомозаики. На качество и точность цифрового ортогофа оказывает большое влияние выбранный метод аэроагригации. В данной статье описывается влияние внешнего метода ориентирования на точность всей аэротриангуляции и в том числе на точность цифровой ортодатомозаики.

Для решения поставленной задачи в работе использовались два самостоятельных проекта сделанных при помощи фотограмметрического программного обеспечения системы PHOTOMOD. В каждом из проектов была сделана цифровая ортодатомозаика с использованием всех элементов внутреннего, внешнего и взаимного ориентирования а также с созданием высокой модели местности. В первом проекте контрольные точки для внешнего ориентирования были выбраны в двойном перекрытии аэроснимков, во втором же проекте в тройном перекрытии. Для анализа влияния выбора контрольных точек внешнего ориентирования на всю аэротриангуляцию и в частности на точность цифровой ортодатомозаики были прометрированы результаты обоих проектов. Были сравнены между собой допустимые разности в координатах контрольных точек в средних квадратических ошибках. Велечина одного пикселя равнялась 0,2м. это и было взято за основу при расчете точности триангуляции. Сравнивая между собой отчеты о триангуляциях составленных программным обеспечением системы PHOTOMOD можно сделать вывод, что при выборе точек для внешнего ориентирования в двойном перекрытии снимков из 6 точек 2 были выше допустимой нормы а в частности точка 10 В составила 0,234 м. и в точке 3 составила 0,414 м. Стоит также отметить, что все точки внешнего ориентирования выбранные в тройном перекрытии снимков были в пределах допустимой нормы.

Ключевые слова: аэрофото, аэроагригация, элементы ориентирования, цифровая ортодатомозаика, высотная модель местности.

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