ScanGIS'2001: Automated Georeferencing of Aerial Images

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Abstract. A method for automated georeferencing of aerial images by means of existing orthoimages and height models is presented. Results with test material of the OEEPE are discussed. The automated process is supported by the use of various thresholds in order to eliminate blunders. Experiences with the settings of these thresholds are discussed. After automatic elimination of some blunders in the automatic measurements a good result for the orientation parameters was achieved: The standard deviation for the residuals at control patches was 1.1 pixel corresponding to 0.9 m on the ground. The proposed method can also be studied at the Internet by means of a learning program.

1 Introduction

Geographic Information Systems have to be complete and up-to-date. Aerial images are the general source of new information. In order to map or extract metric information, the aerial images have to be georeferenced. This means that the ground coordinates of the perspective centre and the spatial position of the camera axis, altogether 6 parameters, have to be known.

If these six parameters are known, mapping of the new information can take place. Various mapping methods exist. One of the most important ones is the generation of a new orthoimage and to digitize new features from it. The orthoimage is also an important layer of a topographic information system, and in many countries a complete coverage exists. In order to renew the orthoimages from time to time and to produce a next generation of orthoimages, efficient and easy-to-handle methods are required. The production starts with the georeferencing of the aerial images, and this sub-process has to be automated so that any non-photogrammetrist can do it as well.

2 Traditional methods

The traditional methods in mapping start with signalizing of control points followed by photography. The orientation data for the images are determined by an aerotriangulation, which includes the measurement of tie and control points in the photographs. Finally, orthophotos are produced from a height model of that area. Usually, a large number of photographs is processed by mapping organisations.

3 New possibilities

Today, the production is carried out digitally. This means that the photographs are scanned and digitised. The measurements of tie points can then be automated and orthoimages are produced in the computer. Furthermore, various databases exist, which include orthoimages, height models, vector maps and much other information on buildings, roads, property, fix points, etc. Such valuable information can be used for the production of a second generation of orthoimages.

4 New demands

The updating of GIS will occur in areas of change. Only one or a few orthoimages have to be produced, but often with a strong time pressure. The production could be done by the users of GIS, or by non-photogrammetrists. Simple and automated procedures are then required. Automated aerotriangulation and positioning of the exposure stations by means of a global position system (GPS) are already used by mapping organisations today, but the required resources for procurement of the software packages, newer cameras and GPS equipment as well as the costs of the drift are not negligible. Cheaper and more efficient methods are also demanded by the mapping industry.

5 A new method

In the proposed method, corresponding pixels in the aerial image and the orthoimage are found by area-based matching. This means that a section of the orthoimage serves as the search area and a section of the aerial image as the target area. The target area is moved pixel by pixel over the search area, and at each position a correlation coefficient is derived. At the position where the correlation coefficient has its maximum, the centre pixel of the aerial image patch (target area) corresponds to one pixel in the orthoimage patch (search area). For both pixels coordinates are derived, either x'-, y'- coordinates in the image or XY-coordinates in the orthoimage. At the XY-position a Z-value is interpolated from the surrounding points of the digital height model (cf. fig. 1). The relation between the image and the object pixel (point), the so-called collinearity equation of photogrammetry, is then applied and orientation parameters are derived by least squares adjustment. The computation is carried out in iterations and the initial values for the unknown parameters are improved after each iteration. A residual remains at each pixel used in the computation and the standard deviation of the residuals, the σ_0 –value, serves as a measure for the achieved accuracy.

The matching of the patches in the imagery of different dates requires time-invariant objects with sufficient texture. Road crossings are such suitable objects. Their positions in a reference system are known from existing topographic databases, and image patches containing such road crossings can be extracted automatically from the orthoimage. In order to extract corresponding image patches from the new aerial image an outer orientation must be known approximately. These patches have to be distributed evenly over the new aerial image. In order to detect and eliminate mismatches thresholds for the maximum correlation coefficients are used.

Fig. 1. Matching between patches of an aerial image and the existing orthoimage is used to georeference the new aerial image. At the position of best-fit spatial (XYZ-) coordinates can be derived from the orthoimage and the height model. Together with coordinates of the image patch centre they serve as input to a bundle adjustment which derives the outer orientation of the aerial image. With these parameters (spatial coordinates of the perspective centre and the spatial position of the camera axis) an aerial image is georeferenced.

The use of area based matching is simple to program and accurate results can be obtained. The suitability of the patches for the matching can be monitored by the size of the maximum correlation coefficient.

The method was first described in [1], and results from experiments with existing software were presented in [3]. Two other authors have also presented solutions to this task (cf. [4], [5]). The European Organization for Experimental Photogrammetric Research (OEEPE) had organized a test where all the new methods used the same data and the obtained results were compared to reference data. Details of this research are published in [2]. Later on a new program in JAVA language was written and results with it are presented in the following chapters

6 Some results with the new method

6.1 Test data

The *aerial image* to be georeferenced was taken from a height of 4100 m in July 1997. The wide-angle colour image has an approximate scale of 1:27 000 and is pretty much centred over the area of the orthoimages and the height model. With a pixel size of 30 µm x 30 µm and a colour depth of 24 bit the file size amounts to 177 Mb. Pictorial information from four *orthoimages* of 2 km x 3 km each was used for the georeferencing of the new aerial image. The orthoimages were produced from a photography taken in June 1995 and have a pixel size of 0.8 m x 0.8 m on the ground. The *digital height model* used in the test had a grid interval of 20 m, and the individual points were accurate with $\sigma = 0.5$ m. The maximum height differences in the covered terrain were only about ± 20 m. More details concerning the used test data are described in [2].

6.2 Derivation of orientation data

The selection of the 15 road crossings was made manually by approximately pointing to them in the orthoimage as well as in the aerial image. Co-ordinates were recorded and image patches extracted. Standard image processing programs were used for this purpose (cziv and img2img of ZEISS Phodis base software). The target was extracted with 31 pixels x 31 pixels that corresponds to 29 m x 29 m on the ground. The search area was selected nearly twice as large: 61 pixels x 61 pixels. Fig. 2 shows three of the selected patches. These image data were converted from colour into grey values and compressed by means of the JPEG scheme and used as input to the new Java program.

The produced program derived for each pair of patches the 'position of best fit' which was then transferred to ground values (XY-coordinates). A height value (Z-coordinate) was derived from adjacent points of the height model using a linear interpolation. The central pixels of the extracted image patches were transformed into image coordinates using the parameters of an affine transformation. (These parameters are sometimes determined together with the scanning of the photographs. A completely automated procedure finds the pixel coordinates for the fiducial marks and compares the coordinates with the ones listed in the calibration certificate of the camera. An adjustment program then determines the parameters of the affine transformation using these two sets of coordinates.)

6.3 Interpretation of the results

The *position of best fit* is found automatically by means of the maximum correlation coefficient. In fig. 2 the result (column and row value) is displayed for three patches as an example. The maximum correlation coefficient for patch nr.13 is, with $r = 0.63$, relatively low. It can be seen, that the vegetation and the shadows differ in these multi-temporal images. These differences are the cause of the poor correlation between both patches.

Fig. 2. Patches of the aerial image and the orthoimage. The matching gave the following results:

Patch No.	position of best-fit col(umn)	row	max. correlation coefficient r_max
13	30	22	0.63
14	19	20	0.76
15	18	20	0.87

The units in the column and row values are pixels

The results of the *bundle adjustment* are the orientation parameters for the new image and an accuracy measure (standard deviation of the residuals). This σ_0-value was as low as 1.1 pixel corresponding to 0.9 m on the ground. Fig. 4 shows the residuals at the different patches. A big error was eliminated when a threshold for the maximum correlation coefficient S1=r_max≥0.7 was used. The remaining residuals are pretty small and irregular (cf. the right diagram in fig. 4). Furthermore, the comparison with manually derived orientation data revealed a good agreement of the perspective centre coordinates (ΔX=0.0 m, ΔY=-1.2 m, ΔZ=-3.1 m). The rotation angles could not be compared due to differences in the applied rotation matrices.

7 Possible improvements

In order to improve the degree of automation as well as the accuracy and reliability of the results some additional measures can be taken. The quality of the initial values, the use of thresholds to eliminate patches with low correlation combined with a check for a sufficient number of remaining patches and their proper distribution over the image area are such measures. Some experiments with the data material will show the value of such measures.

7.1 Quality of initial values

Initial values for the position of the perspective centre and the rotation angles have to be known. These values must not be too far off, in order to work with a reasonable sized search area containing the corresponding parts of the target area. Furthermore, the bundle adjustment program must be able to compute a solution by a few iterations.

The co-ordinates of the perspective centre can be derived from GPS data collected during the flight. The use of a stabilizing mount will produce the lateral and longitudinal rotations of the camera close to 0 grades. The kappa rotation (direction of flight) could also be derived from GPS data. By means of a multi-antenna GPS all the rotations could be derived with an accuracy that is sufficient to start the computation. A better accuracy may be achieved by means of an Inertia Navigation System (INS), which, however, is costly and therefore not commonly available.

Some tests with the above-mentioned data revealed that the used computational program of the author can derive outer orientation parameters even if the initial values are off by several 100 m and a few gon, respectively. The position of the search area can, however, be displaced, so that the target is not contained in the search area. Larger search areas must then be used.

7.2 Setting of thresholds

The automated measurement is not without blunders. A threshold for the maximum correlation coefficient will eliminate some erroneous measurements and the standard deviation will improve. The question is how to find the proper thresholds for automatic processing. Fig. 3 shows the effect of the "threshold 1" for the maximum correlation coefficient on the residual (standard deviation). It is obvious from fig. 3 that the result of the bundle adjustment (size of the residual) improves if patches of low correlation are removed. A "threshold 1" of r_max>=0.65 seems to be appropriate (cf. fig. 3)

On the other hand a removal of measurements will possibly change the distribution of the patches over the image area. Therefore, it should be tested by the program that the area covered with patches is large enough. Fig. 3 also shows the remaining image area (covered with patches) when a threshold for the maximum correlation coefficient is applied. It is obvious from fig. 3 that the standard deviation increases with the decreasing of the covered area. Another threshold "2"can be used, in order to avoid a poor distribution of the patches. For the data used, a threshold of S1 $\geq$ 0.65 for the (maximum) correlation coefficient and S2 $\geq$ 70% for the coverage will ensure a standard deviation of the residuals $\sigma_0 \leq 1$ m at automatic processing.

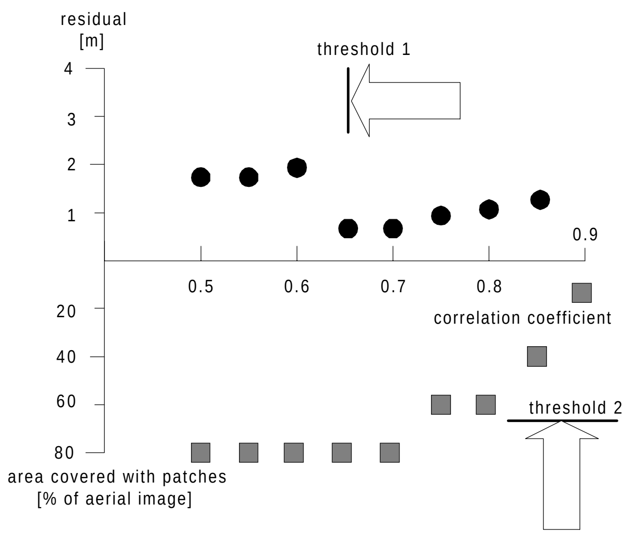

Fig. 3. The effect of selected thresholds on the accuracy of the orientation (standard deviation of residuals). Threshold 1 (for the maximum correlation coefficient) eliminates blunders in the automatic measurements and threshold 2 checks if the remaining image patches cover sufficient image area.

7.3 Detection of blunders

If the above-mentioned measures have been applied, there is still a chance that blunders remain. A simple approach is to scan the residuals after the bundle adjustment. If residuals greater than 3 σ exist, such measurements should be excluded from the computations. Such erroneous measurements could also be down-weighted. It is obvious from fig. 4 that the residual at patch 13 is completely off. Its elimination improves the standard deviation considerably. Therefore, measures to search for blunders should be applied in an automated process.

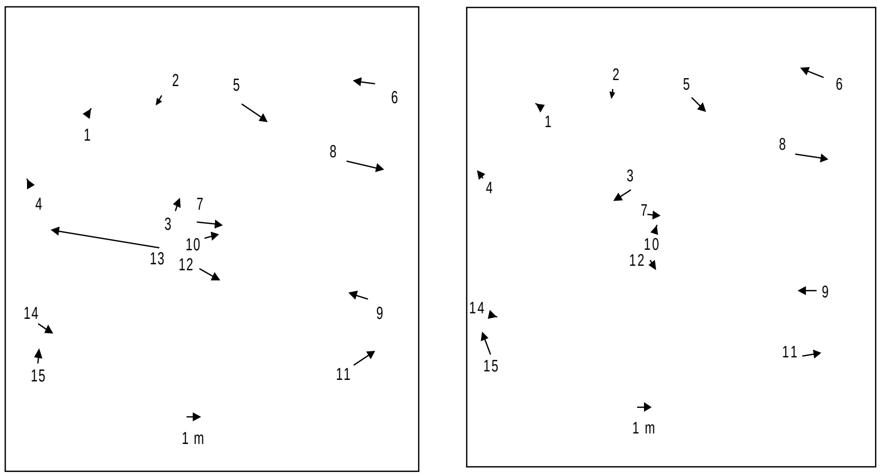

Fig. 4. Residuals after the bundle adjustment. The big error in patch 13 will not be eliminated by a threshold for the maximum correlation coefficient ($S1 \geq 0.60$) or a threshold for the area covered with patches ($S2 \geq 70\%$), but an additional threshold for the residuals ($S3 \leq 3\sigma_0$) will eliminate this point.

8 Conclusion

Further testing with other material is necessary in order to get more experience with the proposed method. More programming is necessary to enable a fully automatic production of orthoimages. The automatic extraction of XYZ-coordinates of road crosses from a topographic database is easily possible. Many more image patches of road crosses are then available for the orientation process. Blunders in the automatic measurements can efficiently be eliminated by a combination of thresholds and robust adjustment, and higher accuracies can be achieved due to the high redundancy in the (automatic) measurements.

Also other database information (such as buildings, lakes and their attributes) can be extracted and serve as control for the automatic georeferencing of aerial images (cf. fig. 5). In general, the proposed method is an example how existing GIS data can be used to automate the map updating.

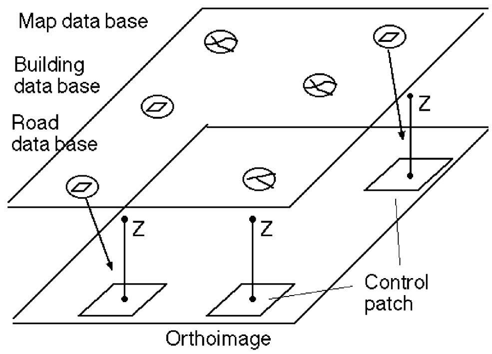

Fig. 5. Extraction of orthoimage patches from various databases. Such patches will be used for the automatic georeferencing of aerial images. The patches may be stored in special databases.

9 Final remark

The described method can be fully automated. It avoids aerotriangulation or the direct georeferencing by means of expensive inertia measuring units. It is therefore less expensive and can be carried out by anyone. The fully automatic production of orthoimages is then possible as well. The method can also be studied by means of an interactive learning program "LDIPInter", which is available on the WWW at the address: http://sunsite.auc.dk/LDIPInter. Some of the experiments described above can be carried out by means of the theme No. 5 of this learning program

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