A NOVEL METHOD FOR AUTOMATING CHECKING AND CORRECTING DEM USING ORTHOPHOTOGRAPHS.

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Abstract
During the development of a new matching algorithm, the need for a tool for automating checking of Digital Elevation Models (DEM) became apparent. The comparison of results from different algorithms is usually done using statistics, but in order to make safe deductions a reference DEM is necessary. If the comparison of algorithms must be done over a variety of pairs, the reference DEMs become a luxury. Therefore an algorithm which could diagnose a DEM without external reference or additional information can be very useful.

This article presents a complete mathematical model, which uses two orthophotos, one from the left photograph and another one from the right, in order to transform the differences between the orthophotographs in precise corrections of the DEM. These corrections are the differences from the real surface and if applied over the existing DEM can produce a more accurate DEM.

INTRODUCTION
The DEM production is currently the bottleneck of the photogrammetric workflow. Automating aerial triangulation (using GPS, INS and proper software) and orthophotograph creation (automatic mosaiking) has stressed the problem. Orthophotomaps are becoming a standard and therefore DEMs become necessary in most photogrammetric projects. On the other hand close range projects for the production of point clouds around objects are becoming more and more attractive to customers.

Although the companies own automating DEM software, the production rate does not rise, simple because the editing needed is almost as time consuming as the manual collection. Personal experience has shown that in a certain project with 60 color photographs of 1:6000 scale, with the DEMs being collected automatically during the previous night, each user could correct 3 models during his shift,. On the other hand if random points and breaklines have been collected manually, 2.5 models per shift of an experienced user could be expected.

A new matching algorithm is being developed in the laboratory of photogrammetry in the University. During it’s last stages, where customization and final adjustments are necessary, the urge of checking the results of different objects in different scales become evident. Manual collection of a reference DEM is the most reliable and obvious solution for comparison, but if a number of models in under investigation then it becomes unpractical and time consuming.

Other possible solutions for checking is the use of internal statistics, which provide a measure of precision but not a measure of accuracy, hence they were also rejected.
Simple overlay of the two orthophotos and abstraction of the gray level values provide a coarse measure for spatial distribution of errors, but not their exact magnitude. Therefore this was also rejected.
Norvelle (1994) has introduced Iterative Orthophoto Refinement (IOR), a method where the discrepancies between the two orthophotos were translated in height displacement and used to correct the initial DEM. The mathematical model of the corrections was simple and approximate. Height correction was being calculated using the approximate formula:
\[ dh = dx \frac{H}{B}, \]
where
\[ dh, \] the height correction
\[ dx, \] the x parallax difference between left and right photo, based on the existing DEM height
\[ B, \] base
\[ H, \] flying height.

Although the formula was approximate, multiple iterations produced promising results. Since 1996, there was no further research or any other report on this subject. The idea of using the discrepancies from two orthophotos to correct the underlying DEM has a strong geometric background and seemed attractive to the authors, who decided to investigate further and work out an exact mathematical model for the height error in any given position using left and right orthophotographs.

METHODOLOGY
Calculation of the height discrepancy is a two step problem. It begins with two matched points as input data and should return a height correction in a position of the DEM.

The algorithm begins with matching in the two orthophotographs (one from the left and another from the right photograph of the pair). If the matched points do not coincide exactly (i.e., do not have exactly the same co-ordinates in the orthophotos), it is obvious that both of them have been imaged wrongly in the orthophotos, hence the true planimetric position of this point is neither of the matched. The first problem is to find the true planimetric position where the height correction should be applied.

The second part is to calculate the height correction, using the displacement of the point from its correct position. After all matched points have produced height corrections in random positions, a new DEM must be produced.

Calculation of the position of the correction.

Planimetric displacement due to height error is always radial to the nadir of the corresponding photograph (Kraus, 1992). If the point’s height is higher than the correct, then the point is going to be imaged in the orthophotograph, closer to nadir (fig.1) and vice versa.

Based on the fact that the displacement due to height error is always radial, the true planimetric position of a point can be calculated as the intersection of the two lines connecting nadir from corresponding matched position in each orthophotographs (fig.2). Hence knowing the xo,yo of the projection centres from the exterior orientation and having the x,y co-ordinates of the matched points is easy to calculate the point where the height correction is going to apply. Having calculate the correct planimetric of the point under investigation, is easy to calculate both radial displacements for left and right orthophotographs (fig.2).

Calculation of the height correction
It is critical to calculate the exact height error in each position using the measured radial displacement. The height error (DZ) can be expressed as a function of the measured radial displacement (DRR).

From the equivalent triangles in figure 3, we have:

\[
\frac{DZ + dZ}{ZOR - ZAR} = \frac{DRR}{RR} \Rightarrow DZ = \frac{DRR(ZOR - ZAR)}{RR} - dZ
\]

where,
- \(DZ\), the wanted correction
- \(dZ\), is the DEM difference between the planimetric position A and AR (calculated from DEM)
- \(DRR\), is the radial displacement (measured on the orthophotographs)
- \(RR\), the distance of AR from nadir (measured on the orthophotographs)
- \(ZOR\), the Z of the projection centre (known from exterior orientation)
- \(ZAR\), the height of AR in the existing DEM

Therefore all the parameters are known and equation (1) can be used to calculate DZ correction.

**FIG.3.** Diagram of height error calculation, with basic quantities. A is the planimetric position in the orthophoto, of the AR, which is erroneously imaged at position A. A is the position in which we are trying to fix the height.

**Final calculation of the height error.**

Since two radial displacements are available, two height corrections can be calculated, which will be different in general, although they apply to the same point. This difference is due to interpolation in grey level values during orthophotograph creation, matching error, DEM inability to model exactly the surface and a number of other approximations. It is quite safe to consider that the final height correction is the average from the two calculated values.

**DISCUSSION**

The only problem with this method is that it is based on the assumption that the only source of error in orthophotos is the DEM. This is not true, although DEM is the important source. External orientation is another important source of error, but aerial triangulation can be double checked quite easily and finalized in a very good solution, while DEM can never be as dense or as accurate as we would like. Besides exterior orientation errors is the less important source of errors (Santrivanopoulos, 1996). On the other hand it wouldn’t be wise to iterate until orthophotos become alike, because we are stressing DEM to incorporate error from all other possible sources.

It should be mentioned that this mathematical model applies only to photographs, where the central projection model is robust and deterministic. Application to satellite models (push-broom model) will be more complicated and a number of assumptions must be taken into consideration.
Another crucial point is that the DEM will probably have problems were the matching has failed. Since the matching itself has failed once there is no reason to believe that the matching in the orthophotographs will be correct. The same problems/reasons for failure will be apparent in the ortho as well.

In any case the final DEM will model the upper surface, or what the photo can see, not the true ground. If there are trees then the final DEM will model the tree height, not the ground height.

Right now a complete program is under development for DEM checking. Results will be tested against a manually collected DEM and therefore conclusions about the robustness of the method would be safely deducted.

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REFERENCES


