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Shorter Contribution

A NOVEL METHOD FOR AUTOMATING THE CHECKING AND CORRECTION OF DIGITAL ELEVATION MODELS USING ORTHOPHOTOGRAPHS

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Abstract

This article presents a complete mathematical model, which translates discrepancies between two orthophotographs created from different photographs, into precise corrections of the Digital Elevation Model (DEM). These corrections are the differences from the real surface and, if applied over the existing DEM, can produce a more accurate one. The mathematical model is straightforward, and is not approximate, and therefore there is no need for iterations.

Possible applications include checking of automatically created DEMs, refinement of existing DEMs using aerial photographs and update of orthophotographs based on the previous DEM and new imagery.

KEYWORDS: DEM, automatic, checking, correcting, orthophotographs, mathematical model

INTRODUCTION

THE PRODUCTION of the digital elevation model (DEM) is currently the bottleneck of the photogrammetric workflow. Automated aerial triangulation (using GPS, INS and proper software) and orthophotograph creation (automatic mosaicking) have 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 nowadays all consulting companies own automatic DEM software, the production rate has not risen, simply because the editing needed is almost as time consuming as the manual collection. Personal experience has shown that in a certain project with 60 colour photographs of 1:6000 scale, with the DEMs being collected automatically during the previous night, each user could correct 3 models during a shift. On the other hand if random points and breaklines have been collected manually, only 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 National Technical University of Athens (NTUA). During its final stages, where customisation and final adjustments are necessary, the urge to check the results of different objects in different scales becomes evident. Manual collection of a reference DEM is the most reliable and obvious solution for comparison, but if a number of models are under investigation then it becomes impractical and time consuming.

Another possible solution for checking could be the use of internal statistics, which provide a measure of precision but not a measure of accuracy, hence this was also rejected.

Simple overlay of the two orthophotos and subtraction of the grey level values provide a coarse measure for spatial distribution of errors, but not their exact magnitude. Therefore, this was also rejected.

Norvelle (1994) introduced iterative orthophoto refinement (IOR), a method where the discrepancies between two orthophotos are translated in height displacement and used to correct the initial DEM. Although theoretically the orthophotograph should be independent from the initial photograph, in practice orthophotographs created from different photographs differ slightly. The mathematical model of the corrections is simple and approximate. Height correction is calculated using the approximate formula:

$$dh = dx\frac{H}{B},$$

where dh is the height correction, dx the x difference (in ground units) between orthophotographs created from the left and right photographs of a pair, B the base, and H the flying height.

Although the formula is approximate, multiple iterations produced promising results. Since 1996, to the authors' knowledge there has been no further research nor any other report on this subject. The idea of using the discrepancies between 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 orthophotographs created from the left and right photographs of a pair (from here on referred to as the 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 left and right orthophotographs. If the matched points do not coincide exactly (that is they do not have exactly the same geodetic coordinates in the orthophotos), it is obvious that both of them have been imaged wrongly in the orthophotographs. In this case none of the points were created with the correct height. 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 could be produced.

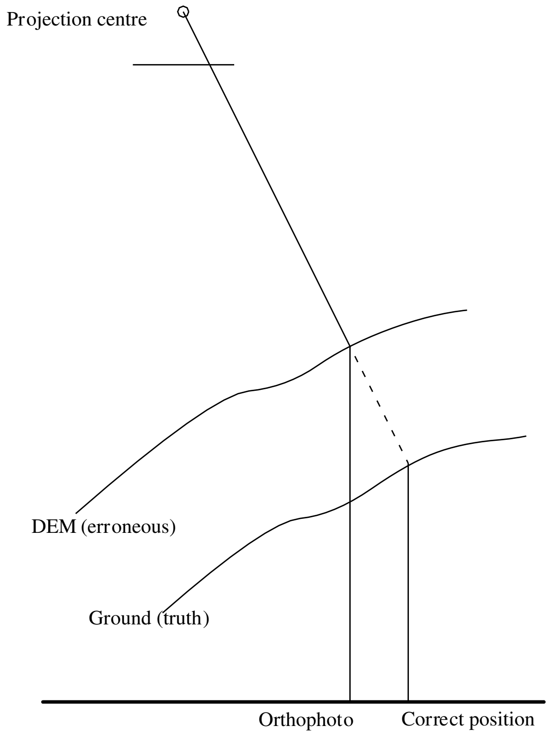

FIG. 1. Radial displacement according to height error.

Calculation of the Planimetric Position of the Correction

If the matched points in the two orthophotos do not have the same ground coordinates (do not coincide), then both of them are erroneous (the only case when this statement is not true is when the point under investigation is in the nadir position in either of the two aerial photographs, because in this case height does not have any effect on planimetric position).

In order to calculate the exact planimetric position, where the height correction (or checking) should apply, it should be kept in mind that 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 one, then the point is going to be imaged on the orthophotograph, closer to the aerial photo nadir (Fig. 1) and vice versa.

Provided that the planimetric displacement is caused only because of the height error of the DEM, then the displacement is radial. Therefore, the correct planimetric position of any point is somewhere along the ray connecting the matched point and the nadir of the aerial photograph from which the orthophotograph has been created. Any displaced point in a georeferenced orthophotograph has ground planimetric coordinates of X,Y and the nadir point of the corresponding aerial photograph can be

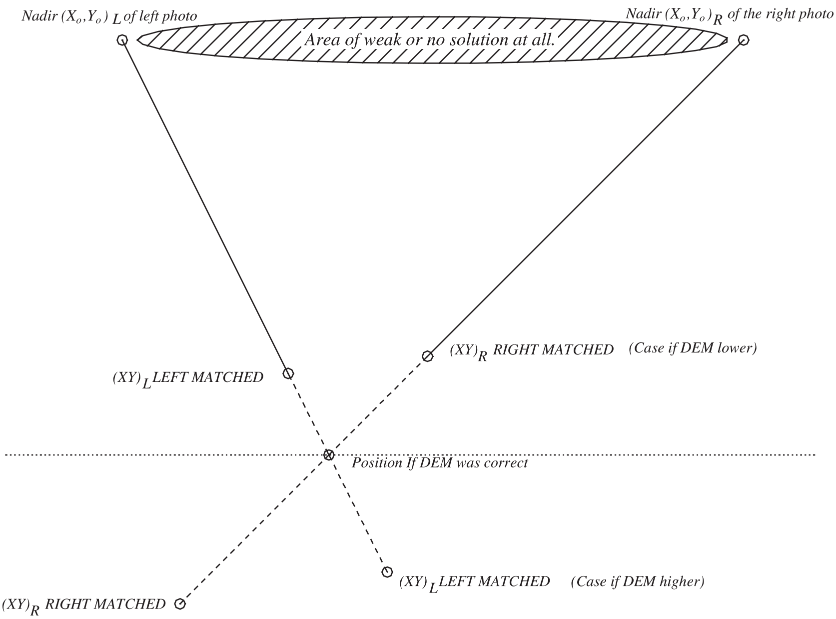

FIG. 2. Diagram showing the points' planimetric positions (ground coordinates) for the calculation of the position of the correction application. In any case (higher or lower DEM than the correct height), the two lines should intersect in the correct position of the point under investigation.

found from the absolute orientation of the photograph. Hence, if the projection centre of the photograph is X_o,Y_o,Z_o, then the planimetric coordinates of the nadir are X_o,Y_o and the true planimetric position of the point under investigation lie somewhere along the line connecting X,Y and X_o,Y_o.

Therefore for the pair of matched points, there are two lines connecting the displaced points with the corresponding nadir points ($(X,Y)_L,(X_o,Y_o)_L$ for the left photograph and $(X,Y)_R$, $(X_o,Y_o)_R$ for the right photograph) (Figs 2 and 3). With the two lines analytically expressed it is easy to find their intersection. In any case the intersection of the two lines is the true planimetric position of the point under investigation, which is represented in the two orthophotographs by the matched points.

With the true planimetric position of the point found, it is easy also to compute the radial displacement due to height error, resulting in two displacements (*r*1 and *r*2 in Fig. 3), one in each orthophotograph.

From Fig. 2 it becomes apparent that, for points along the line connecting the two nadir points, there is no solution. On a certain area near this line, the intersection of the lines is weak and computer solution might cause numerical errors. Provided the checking is being done on grid points, it is unlikely to check a point exactly on this line. In order to be on the safe side, an algorithm which excludes such points from the checking seems the best remedy. After completion of the whole model, interpolation from nearby points can fill possible gaps in the grid.

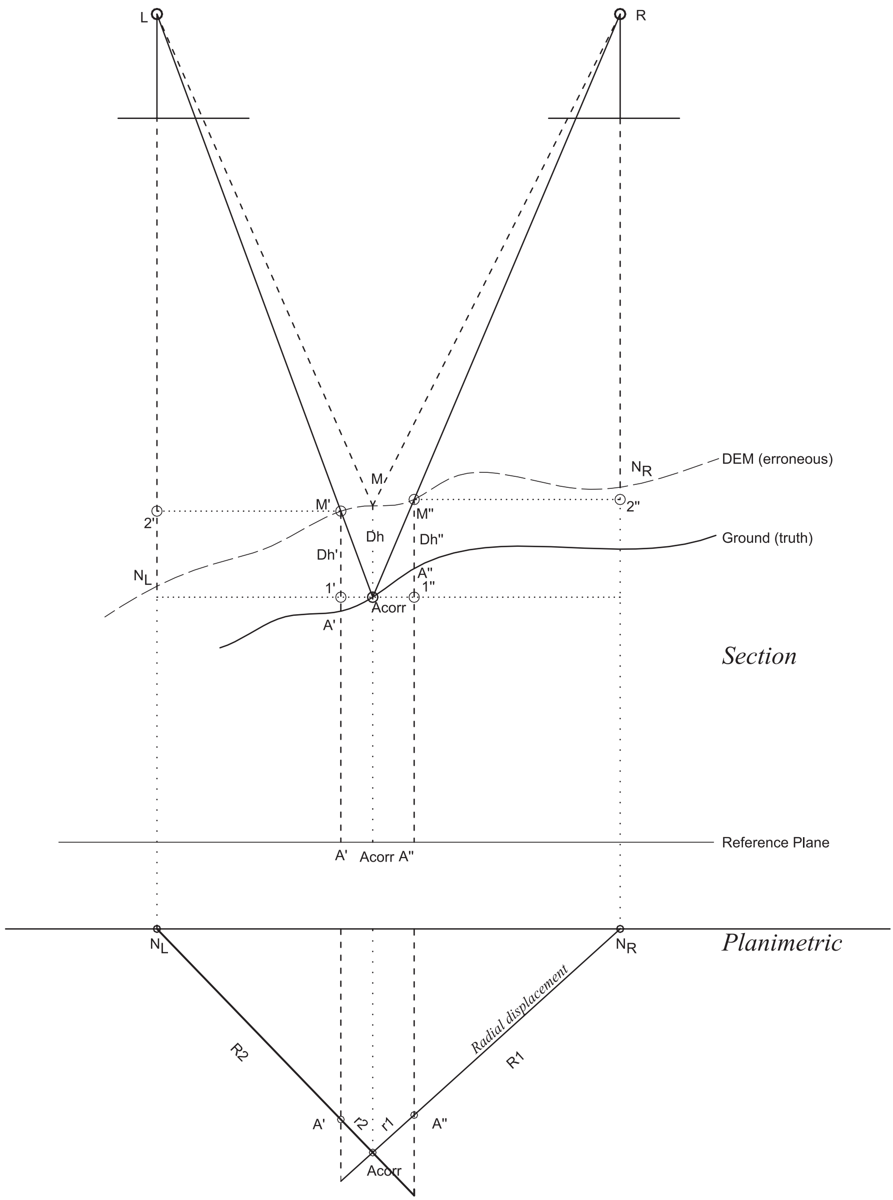

FIG. 3. Diagram of height error calculation for the right photograph, with basic quantities. *A* is the planimetric position in the orthophotograph, of the *AR*, which is erroneously imaged at position *A*. *A* is the position in which we are trying to fix the height.

Calculation of the Height Correction

It is critical to calculate the exact height error in each planimetric position. The basic quantities can be seen in Fig. 3, which requires some explanation:

L,R	are the projection centers of the two photographs, whose orthophotographs are under investigation
NL,NR	nadir points (planimetric) of the projection centres, both known from exterior orientation
A_{corr}	is the point under investigation, whose correct planimetric position is known, as an intersection of two lines, but whose height is the basic unknown if we are trying to correct the DEM.
A', A''	are the wrong images on the orthophotographs of the (same) point under investigation. This point has been imaged in two positions due to erroneous DEM. If the DEM have been correct then their position should coincide.
M', M''	imaginary points in space, representing the wrong heights of A' and A''. These heights are known and can be calculated from the erroneous DEM.
M	the wrong height of A_{corr}. Known as it can be calculated using interpolation in the erroneous DEM on the point A_{corr}.
Dh	the difference on A_{corr}. It is the basic quantity if we are only checking the DEM correction which should be applied to M, and therefore this is the basic unknown quantity
Dh'	difference of A_{corr} from M', unknown.
Dh''	difference of A_{corr} from M'', unknown.

Since M' and M'' are of known height, calculation of Dh' or Dh'' would provide the correct height on A_{corr}. From similar triangles $R2''M'' = M''1''A_{corr}$ in Fig. 3,

$$\frac{R2''}{M''2''} = \frac{Dh''}{1''A_{corr}} \Leftrightarrow Dh'' = \frac{R2''}{M''2''} 1''A_{corr} \quad (1)$$

where,

$M''2''$	can be calculated from the right orthophotograph and equals $R1$ in Fig. 3,
$1''$	A_{corr} can be calculated from the right orthophotograph and equals $r1$ in Fig. 3,
$R2''$	is the height of the right projection centre minus the erroneous height M'', which was used to calculate A''.

Hence Dh'' and similarly Dh', can be calculated exactly.

Final Calculation of the Height Error

From left and right orthophotographs we can calculate two corrections and therefore:

$$M' + Dh' = A_{corr} = M'' + Dh'' \quad (2)$$

Obviously, the first and third parts of equation (2) will not be exactly the same due to a number of imponderable factors such as 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 always true, although the DEM is undoubtedly an important source. Exterior orientation is another important source of error, but aerial triangulation can be double checked quite easily and finalised in a very good solution, while DEM can never be as dense or as accurate as one would like. Besides exterior orientation errors are less probable than errors or inadequacies in the DEM. On the other hand it wouldn't be wise to iterate until orthophotos become alike, because we are stressing DEM to incorporate errors 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 (pushbroom model) is possible provided a number of assumptions concerning exterior orientation are taken into account.

Another crucial point is that the DEM will probably have problems where 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 or reasons for failure will be apparent in the orthophotographs as well. This method could be useful in cases where there is an existing DEM which should be updated or checked. Such cases include:

(a) update of orthophotographs using new photography and the old DEM;
(b) checking DEMs created using image matching techniques; and
(c) creation of orthophotographs using DEM from maps.

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.

A complete program is currently under development for DEM checking, in order to test the algorithm under real conditions. Results will be tested against a manually collected DEM and therefore conclusions about the robustness of the method would be safely deduced.

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Résumé

On décrit dans cet article un modèle mathématique complet qui traduit les écarts entre deux orthophotographies, réalisées à partir de photographies différentes, en corrections précises du modèle numérique des élévations (MNE). Ces corrections sont les écarts avec la surface réelle, de sorte qu'une fois appliquées au MNE existant il en résulte un MNE plus précis. Le modèle mathématique opère directement, de façon rigoureuse et ne nécessite donc pas d'itérations.

Les applications envisageables comprennent le contrôle des MNE obtenus automatiquement, l'affinement des MNE existants en utilisant des photographies aériennes et la mise à jour des orthophotographies établies avec des MNE antérieurs en profitant d'une nouvelle imagerie.

Zusammenfassung

In diesem Beitrag wird ein komplettes mathematisches Modell beschrieben, das Unterschiede zwischen zwei Orthophotos, die aus verschiedenen Photos generiert wurden, in präzise Korrekturen für das Digital Höhenmodell (DHM) umsetzt. Diese Korrekturen beschreiben die Differenzen zur realen Oberfläche, und können, wenn über das komplette DHM angewandt, dessen Genauigkeit erhöhen. Das mathematische Modell ist streng und nicht genähert, und daher sind keine Iterationen erforderlich.

Es sind u.a. folgende Anwendungen denkbar: Kontrolle von automatisch generierten DHMs, Verbesserung eines bestehenden DHMs mit Hilfe von Luftbildern und eine Fortführung von Orthophotos, basierend auf das dafür verwendete DHM und die neuen Bilddaten.