

# AUTOMATING THE CHECKING AND CORRECTING OF DEMs WITHOUT REFERENCE DATA.

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### ABSTRACT:

The need for Digital Elevation Model (DEM) checking has raised since the automated matching techniques emerged. The use of reference data is a luxury and therefore cannot be used in all cases. This article presents a completely new mathematical model, which translates discrepancies between two orthophotographs created from different photographs, into 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 one. The mathematical model is straightforward, does not approximate, and therefore there is no need for iterations.

In order to test the algorithm a reference DEM has been manually collected and distorted with a known pattern. The corrections produced by the algorithm follow the known pattern. Tests over automatically created DEMs by commercial software has also been made and compared against the reference DTM. Obvious 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.

## 1. INTRODUCTION

Digital Elevation Models (DEMs) are currently the bottleneck of the photogrammetric workflow. Automation of aerial triangulation (using GPS, INS and proper software) and orthophotograph creation (automatic mosaicing) has stressed the problem. The need for orthophotomaps, which are becoming a standard and therefore the need for DEMs, city models and telecommunication industry expansion are stressing the demand of large updated and accurate DEMs. On the other hand close range projects for the production of point clouds around objects are becoming more and more attractive to a wide range of customers.

Manual collection of points is laborious and extremely slow. Digital stereoplotters are becoming cheaper than the past, but are still expensive hence usually operators work in shifts. Automated matching methods seem to be a solution, but proved valid only for small scales, and there is always the need for corrections, or at least visual checking, which means valuable stereoplotter time (ISM, 1998). A completely automated method, which could work unsupervised 24 hours a day, in a simple computer is very attractive. So the main problem is how to check and correct the automatically created DEM, without human intervention. The same problem also holds for large national organisations, which must check subcontractors and delivered DEMs.

A new matching algorithm is being developed in the Laboratory of Photogrammetry in National Technical University of Athens (NTUA). During its last stages, where tuning and final adjustments are necessary, the urge of checking the results upon different objects in different scales became 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.

A simple solution for checking could be the use of internal statistics, which provide a measure of precision but not a measure of accuracy (Zhilin, 1993a; Zhilin, 1988), was rejected.

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

Norvelle (1994; 1996) has introduced Iterative Orthophoto Refinement (IOR), a method where the discrepancies between two orthophotographs created with the same DEM but from different aerial photographs, were 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 was simple and approximate. Height correction was calculated using the approximate formula:

$$dh = dx \frac{H}{B} \quad (1)$$

where

dh = height correction

dx = the x difference (in ground units) between orthophotographs created from the left and the right photographs of a pair

B = base

H = flying height.

Although the formula was approximate, a couple iterations produced promising results. Since 1996, there wasn't any other report on this subject that the authors are aware of. The idea of using the discrepancies between two orthophotographs to correct the underlying DEM has a strong geometric background and seemed attractive to the authors, who decided to investigate further and work out a precise mathematical model for the height error in any given position using orthophotographs created from left and right photographs of a pair (from now on referred freely as left and right orthophotographs).

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## 2. METHODOLOGY

The principle of the method is quite simple. Using the DEM under investigation, one can produce two orthophotographs from two different photographs. Matching the two orthophotographs and running the suggested mathematical model, a TIN with DEM discrepancies can be calculated. Running statistics over this TIN leads to checking of the initial DEM while addition of the TIN to the DEM produces a more accurate DEM.

Calculation of the height discrepancy is a two-step problem. It begins with two matched points in left and right orthophotographs as input data and should return a height correction in a specific position of the DEM. The calculation of the height correction is one thing, and the calculation of the exact position is another. It is not to forget that if the matched points in the two orthophotographs do not coincide (that is they do not have exactly the same geodetic coordinates), neither of them is correct, hence the exact position must be calculated. The key point is that the planimetric displacement due to height error is always radial to the nadir of the corresponding photograph (Kraus, 1992).

It is critical to calculate the exact height error in each planimetric position. The basic quantities can be seen in figure 1, and the basic formula for the height discrepancy calculation is

$$\frac{R2''}{M'2''} = \frac{Dh''}{I'' \text{ Acorr}} \Leftrightarrow Dh'' = \frac{R2''}{M'2''} I'' \text{ Acorr} \quad (2)$$

Hence  $Dh''$  and similarly  $Dh'$ , can be calculated exactly. The final  $Dh$  on the point can be the average of the two values. The complete theoretical model is detailed described by Georgopoulos and Skarlatos (2003).

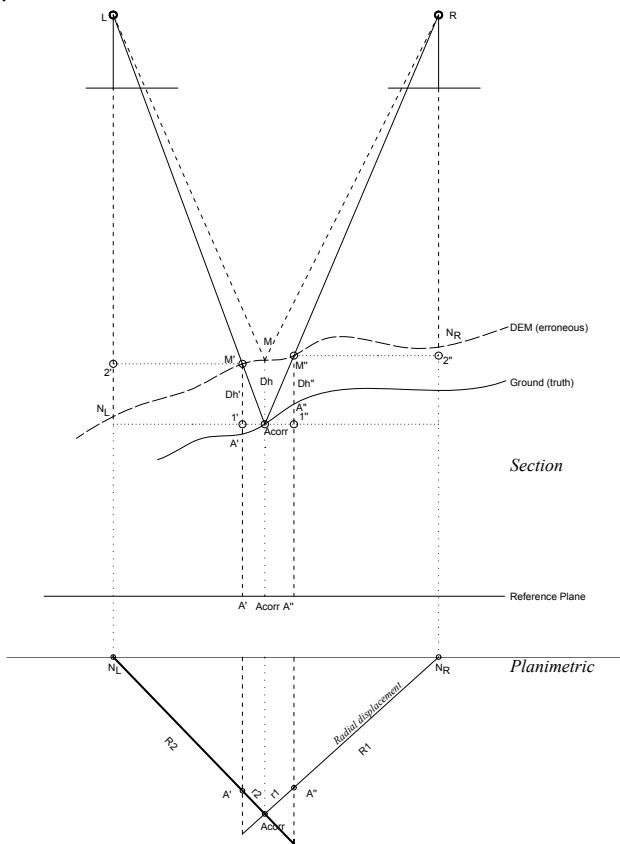


Figure 1. Diagram of the basic concept of the proposed method.

## 3. TEST AREA.

In order to test thoroughly the proposed algorithm, a manually collected DEM was necessary. It must be noted that the manually collected DEM was only to test the integrity of the proposed algorithm. The algorithm itself is designed to work without reference DEM in any area.

The test area has been selected from 1:17000 scale colour photographs. It is equal to half photogrammetric model and can be seen in figure 2. It is 1500x1200 meters and the height range is 58 meters, with minimum and maximum of 54 and 169 meters respectively. The flying height was 2650 meters above mean sea level. The original photographs were scanned at 21 microns, or 0.364 meters in ground unit. The area selected includes many features namely a quarry, agricultural and semi urban areas, being ideal for testing.

The collection of the DEM has been done with 10 meters grid spacing in a Z/I SSK stereoplotter. The operator had the ability to move up to 7 meters from the predefined grid position, meaning that the collected points form a TIN rather than a DEM.

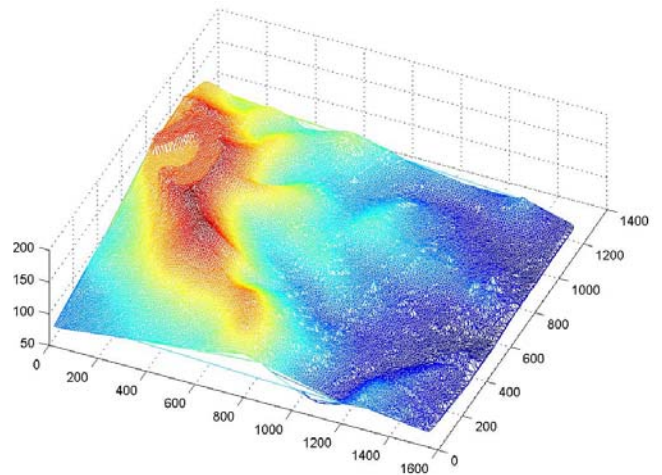


Figure 2. Manually collected TIN and orthophotograph of the test area.

In order to evaluate the precision of the manually collected DEM, 14 repetitive measurements in 16 points of different background, approached from accidental addresses have been made. The average standard deviation of these measurements is a measure of precision and was 0.147 meters. Theoretically the expected height accuracy in a single point is equal to the pixel size in ground units for a 152 mm lens and a base of 90

mm (ISM, 1998). The precision of the measurements is less than half of the pixel size in ground units, hence better than the theoretical accuracy expected.

#### 4. TESTS AND VALIDATION OF THE PROPOSED METHOD.

##### 4.1 Application over synthetically distorted data.

The first attempt to check the algorithm was based on an artificially distorted DEM. An inclined plane (fig. 3) has been calculated and added to the manually collected DEM, ranging from +4 to -5 meters. From this distorted DEM two orthophotographs were created, one from the left and one from the right photographs of the pair used for the manual collection of the DEM points. The orthophotographs were covering the aforementioned area (fig. 2) with a ground pixel size of 0.25 meters.

The proposed algorithm has been applied on the two orthophotographs. A combination of a feature and area based matching algorithm was used incorporating adaptive template and elliptical areas instead of the standard square templates (Skarlatos, Georgopoulos, 2004). It is essential to note that the algorithm provides matched points in an almost predefined grid, but the feature extraction slightly distorts the grid (Forstner, 1986) so that to match in interest points. In addition it doesn't interpolate, nor fixes the grid in the predefined positions, returning a TIN. Therefore it is quite often to have small gaps particularly in areas where the grey tones are smooth.

The matching has been performed with a 25 pixel spacing (equals to 6.25 meters in ground units) and maximum template of 1521 pixels (equivalent to 39x39 square template), necessary for the quarry area, where there is no adequate grey tone variation. The resulting estimated corrections, filtered with a rotational filter (Sonka et al, 1993) can be compared with the artificial distortions (inclined plane) in fig. 3. It is obvious that the algorithm has correctly detected the pattern of the inclined plane. There are of course some undulations and the covered area is a bit smaller than the original, because the matching algorithms cannot match pixels on the edge of the image. The reasons of the undulations are the aforementioned problem of matching points close to the edges and the DEM interpolation, necessary for visualization of the differences, especially along the edges where missing points create problem in the interpolation.

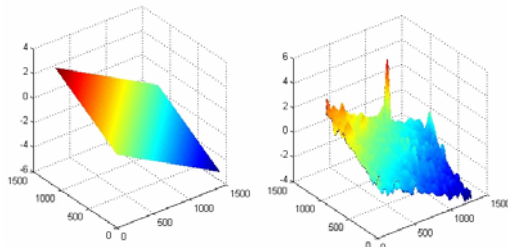


Figure 3. The artificial difference applied to the original DEM, and the differences detected from the algorithm as filtered DEM. The peak is due to interpolation, since there were no points measured in the close vicinity.

In order to verify that the algorithm is working properly, it was necessary to apply the proposed corrections by the algorithm to the distorted DEM under investigation and

compare it to the manually collected DEM. The algorithm returns X, Y, dZ coordinates in random positions. In order to compare it with the reference data, which are also in TIN format (manually collected) it is necessary to convert one of the two in DEM format. It is obvious that during this interpolation there is some loss of accuracy (Al-Tahir et al, 1992). It was decided to convert the manually collected TIN in DEM with 5 meters grid spacing. This ensures that the deterioration will be hopefully held at a minimum. The corrected points from the algorithm are then compared to this surface and the differences from it are calculated and statistically analyzed. In order to reduce the mismatches of the matching algorithm, the mean (expectance zero) and standard deviation of the corrections is calculated and a 95% two-tail reliability check is performed on the corrections. This is more like an internal precision check, without any external data, which can be performed easily and does not affect the validity of the proposed algorithm. The remaining values are also statistically analyzed and presented in fig. 4. The corrected DEM (the filtered one) has a mean of -0.11 meters, Standard Deviation (SD) 0.59 meters, Mean Absolute Deviation (MAD) 0.36 meters and Root Mean Square (RMS) error 0.60 meters. Two conclusions can be easily deduced from these measures:

The mean of the corrected DEM is well under the precision of the manually collected points

The MAD is equal to the expected accuracy (one pixel in ground units, ISM 1998).

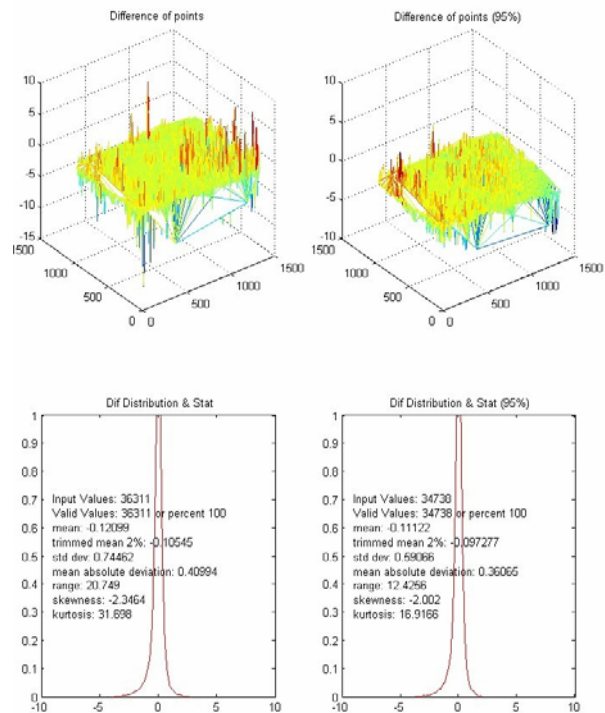


Figure 4. Visualization and statistical analysis of the differences between the manually collected and the corrected by the algorithm DEM.

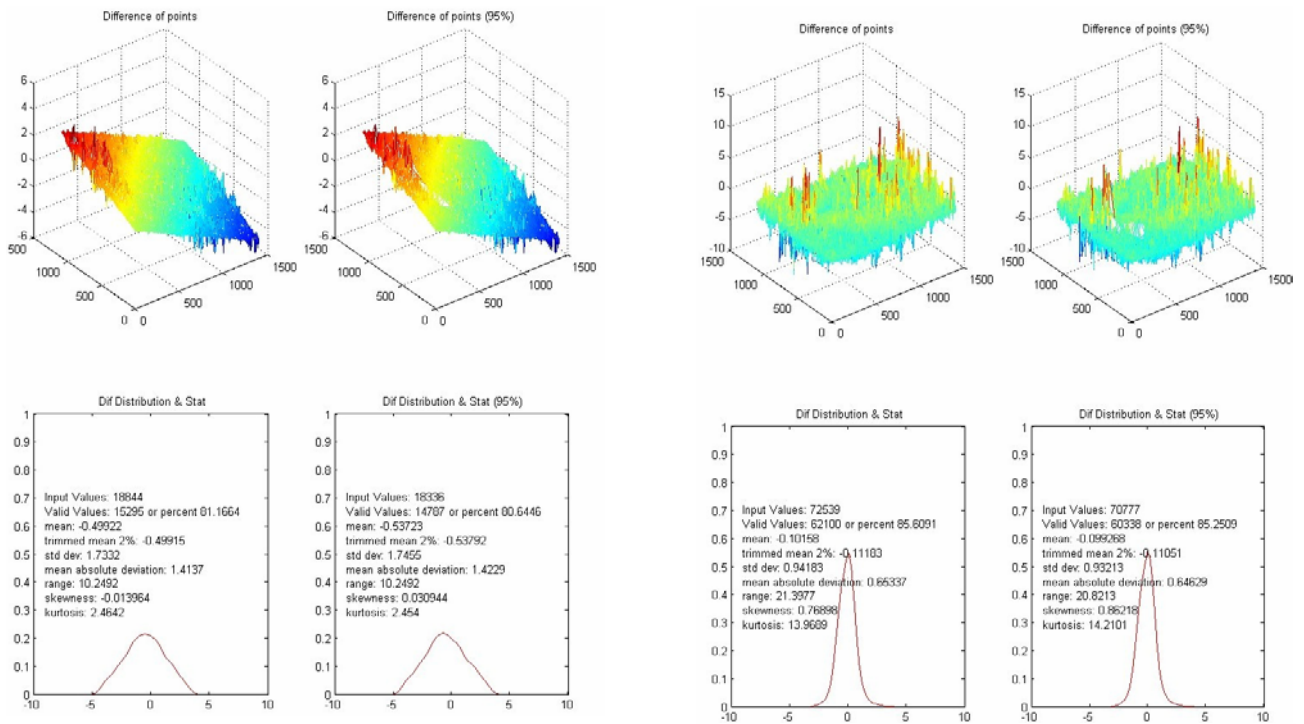


Figure 5. Visualization and statistical analysis of the differences between the manually collected and the artificially distorted DEM (prior to correction).

These values become much more elegant and impressive if one considers the same statistics for the DEM prior to corrections (fig. 5). The improvement of the shape of the error distribution is devastating. Values of the statistical analysis also justify the fact that the uncorrected DEM is much worse than the corrected one; mean -0.54, SD 1.74, MAD 1.42 meters and RMS 1.82.

#### 4.2 Application of the method over automatically collected DEMs.

A recent research in the National Technical University of Athens, laboratory of photogrammetry, concerned with image matching in color images, has automatically created 24 DEMs using different software (Vision's Softplotter, Erdas OrthoPro and Z/I SSK). In order to test algorithm's integrity over real data, two DEMs created with Softplotter have been selected for testing with the proposed algorithm. Softplotter allows the user to decide whether he wants the collected points to be in a regular spacing or in random positions, producing respectively Digital Terrain Model (DTM) and Triangulated Irregular Network (TIN), accordingly to software's parameters (from now on, both freely referred as DEMs). The final surfaces are not same, basically due to the different approach in the collection procedure rather than to the final interpolation performed at the last step.

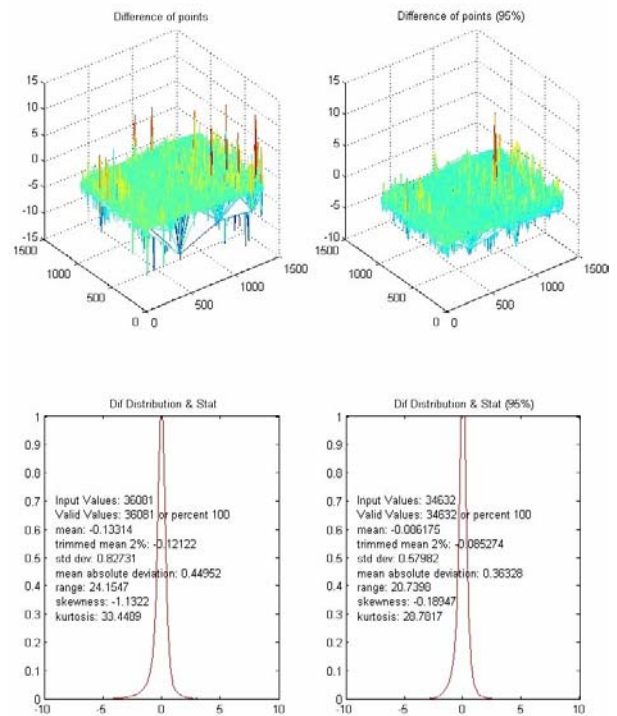


Figure 6. Initial (upper) and corrected DEM (lower) comparison with the manually collected TIN. Visualization and statistics of the DEM collected with the "DTM" method on the Softplotter.

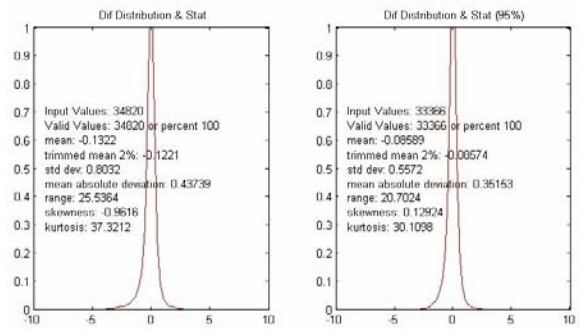
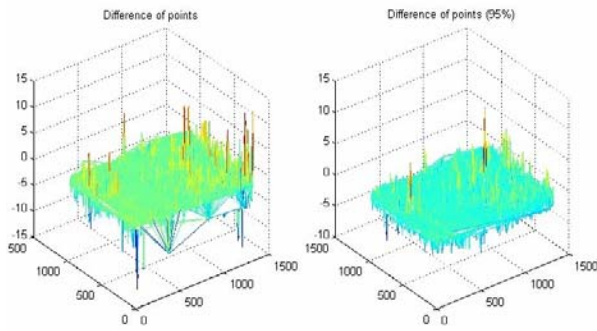
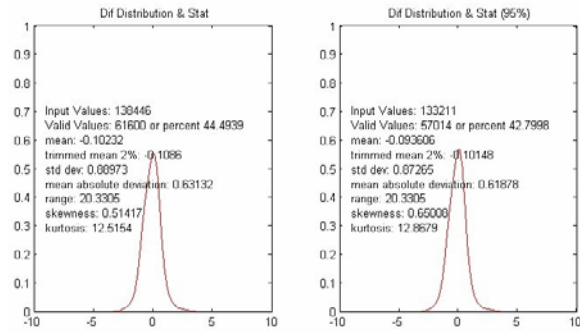
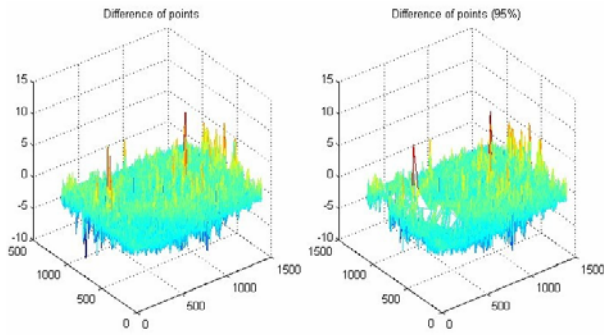


Figure 7. Initial (upper) and corrected DEM (lower) comparison with the manually collected TIN. Visualization and statistics of the DEM collected with the “TIN” method on the Softplotter.

## 5. RESULTS

Although the tests conducted returned a number of measures for statistical analysis, only the most important are summarized in the following table.

DEM type	Mean m	SD m	RMS m	MAD m	Range m	Kurtosis	
Distorted	Initial 95%	-0.54	1.75	1.82	1.42	10.25	2.45
	Corrected 95%	-0.11	0.59	0.60	0.36	12.43	16.92
DTM	Initial 95%	-0.10	0.93	0.94	0.65	20.82	14.21
	Corrected 95%	-0.09	0.58	0.59	0.36	20.74	28.78
TIN	Initial 95%	-0.09	0.87	0.88	0.62	20.33	12.87
	Corrected 95%	-0.09	0.56	0.56	0.35	20.70	30.11

Table 1. Comparison of the initial and corrected by the proposed method DEMs, against the manually collected TIN.

These statistical measures are well known and widely used, but a brief explanation is given. Mean is a measure of central tendency, and shows if there is a significant systematic shift of the surface, indicating a gross error. It is a measure of accuracy, although it is highly dependent on the outliers. Considering the expected accuracy (0.36 meters) and human operator’s precision (0.147 meters), all DEMs have mean close to zero, except the artificially distorted DEM, which correctly indicates a large error. Generally speaking all software packages are able of producing DEMs with mean better than the operator’s precision. Balanced errors such as these in the artificially distorted DEM cannot be detected by the mean.

SD and MAD from the mean, are measures of the DEM’s dispersion. They are a measure of precision. SD shows the magnitude of the variations from the mean value, while MAD is a measure of the mean difference.

RMS error is the most appropriate measure when comparing with reference data. It is the DEM’s accuracy. In this particular case where the mean is small, there is negligible difference between RMS and standard deviation.

Range shows the maximum variation and is a measure of dispersion of the differences between the compared DEM with the reference.

Kurtosis is a numerical value of how close the error distribution plot is to the Gaussian plot. If kurtosis is equal to 1, the plot is exactly the Gaussian plot. If lower than 1 then it is very wide (hence large errors and very big standard deviation) and if larger than one is very thin and high, meaning that all the values are concentrated close to the mean (hence small errors).

Conclusions that can be drawn comparing values of table 1 are the following:

Arithmetic mean was improved in all cases by the algorithm, especially in the artificially distorted DEM, where the improvement was noticeable.

In all case the algorithm improved SD, irrespectively from the beginning value of the initial DEM. The final values were 0.56-0.59 meters.

Exactly the same holds with RMS. The only difference is that the RMS is a bit bigger than SD because it ‘encloses’ the mean.

In all case the algorithm improved MAD, irrespectively from how erroneous was the initial DEM. The final value was 0.36 meters, which is equal to the expected DEM accuracy, accordingly to ISM (1998) and equal to one pixel in ground units (for the particular project parameters).

Algorithm has not improved range at all. Actually in the distorted DEM there was a noticeable deterioration. It is suspected that the large values appearing in range is a side

effect of matching and large remaining blunders, which cannot be avoided. That's why in the distorted case there was deterioration, while in the automated DEMs, there was no noticeable difference.

The error distribution plots show a noticeable improvement after applying the algorithm. The measure of this effect is kurtosis, which has been improved hugely.

## 6. CONCLUSIONS AND FURTHER RESEARCH.

From the arithmetic point of view, the main problem of the automatically collected DEMs is the dispersion from the real surface due to the matching and sampling of the ground.

It is quite obvious that the method can calculate corrections in DEMs and improve their accuracy (RMS) by 37% (real data case), and their precision (SD, MAD) by 40% approximately.

The most interesting fact is that the algorithm was able to improve MAD, SD and RMS, ending in the same values in any case, irrespectively of the magnitude of the initial error. This fact confirms the initial statement that the method does not need iterations to work.

MAD has been reduced to the theoretical height accuracy of a single measurement. This is particularly promising especially if one considers that the comparison enclose a necessary step of interpolation, which deteriorates the results (Al-Tahir et al., 1992; Zhilin 1993b).

What's makes the method even more attractive is the fact that it can be used in a number of cases such as:

correction and creation of a more accurate DEM

checking of automatically created DEMs

updating of previously existing DEMs, using recent aerial photographs

change detection based on activities concerning DEM change, such as road creation, quarry development, urbanisation, etc.

Extensive tests on a number of different aerial or close range photographs, with different scale, created by different digital stereoplotters, hugely distorted DEMs etc, are currently running with promising results.

Since the algorithm can effectively correct the DEM, these corrections can be used for checking. An efficient way to investigate the quality of the created DEMs is also under investigation.

## ACKNOWLEDGEMENTS

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