

AUTOMATIC EXTRACTION OF 3D MODEL COORDINATES USING DIGITAL STEREO IMAGES

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ABSTRACT

At the Remote Sensing Laboratory of the University of the Aegean (RSLUA) a new approach for the automatic extraction of 3D model coordinates from digital stereo pairs has been developed. The technique proposed ignores the actual photogrammetric equations and treats the problem in a general way independent from the type and form of the digital stereo images. This is achieved by making extensive use of polynomial mapping functions to approximate and simulate the individual image and model geometry. No knowledge of the actual source of the stereo images is required. At the same time, the use of polynomials results in a fast calculation cycle suitable to be implemented on personal computers without special hardware requirements. The polynomials are used by a simple image matching algorithm to determine elevation data. Polynomials are also used to calculate planimetric data. The form of the polynomials used is automatically determined using suitable check point data. Further more, two simple criteria are used to automatically locate and remove blunders. The proposed model is described here and test results from two parts of a SPOT stereo pair and the overlap area of two aerial photographs scanned with an ordinary A4 DTP scanner are presented.

1 INTRODUCTION

Photogrammetry and photogrammetric techniques in general, have been used in the past for accurate measuring purposes in a wide field of sciences and practices. In order to apply these techniques to extract 3D model coordinates, a suitable stereo pair of the object of interest must be available. The extraction is a point-by-point process which used to be manual. With the development of analytical stereoplotters, the process became semiautomatic. Nowadays the availability of digital images and digital photogrammetric stations, offer a cost effective method for almost any visual-based measuring purpose of our 3D environment. This is achieved through the automation of the individual photogrammetric steps e.g. coordinate transformation, fiducial point measurements, parallax elimination, etc. Human operators are still required and they play a major role in the whole process.

Fully automated processes are unquestionably a faster and less expensive approach. According to the current practices followed in digital photogrammetry, such processes need to deal with two main problems. First, the digital images from the various possible sources (e.g. satellite images, scanned aerial photographs, video images etc.) have to be transformed into the frame geometry. Then, an image matching technique must be applied to accurately locate homologous points on the overlap area of the two images of the stereo pair. This way, the well-known mathematics of classic photogrammetry (e.g. collinearity condition) can be readily applied to determine the 3D coordinates of the corresponding object points.

The development and use of geometric correction models require a full and in depth understanding of the digital images' recording source. This usually results in complex mathematical formulations in order to take into account all known systematic and non-systematic parameters that influence the image geometry. This is especially true when satellite and non-photogrammetric imagery is involved e.g. images from DTP scanners. In some cases accurate calibration data must be pre-exist. Extra GCPs (ground control points) or other utility data can be used to help estimate the unknown or simplified parameters.

The process of automatically locating corresponding image points on the overlap area of the stereo pair is known as *image matching*. It can be performed using either previously extracted feature characteristics (feature based matching)

or pixel intensities (area based matching). Both methods are known to give sub-pixel accuracy under ideal conditions but they are influenced by the underlying geometric model used and they are computationally expensive (Trinder et. al., 1994).

A new approach has been developed at the RSLUA for the automatic extraction of 3D model coordinates using digital stereo images. The proposed model was initially built for the automatic elevation extraction from digital SPOT stereo images. Later, it was successfully applied without any kind of modification to the overlap area of a scanned (using an ordinary DTP scanner) aerial photograph stereo pair. This is to say that the proposed approach deals with the problem in a uniform and general way independent from the type or form of the digital stereo images that is applied to.

This paper describes this technique in the context of near-vertical digital images of ground but it can be easily extended to virtually any type of image. Test results from two parts of a SPOT digital stereo pair and the overlap area of scanned aerial photographs are also presented.

2 PROPOSED MODEL

2.1 Geometric Model

In the proposed model the transformation to frame geometry and the other classic photogrammetric equations are missing. Instead, the underlying image and ground geometry together with their interrelationship, is simulated and approximated by direct mapping functions (polynomials). This is not new as such; for example, Kratky (1989) proposed a similar approach for the fast real-time positioning of SPOT stereo photographs in analytical stereoplotters. The polynomial mapping functions compared to the strict transformations are faster and easier to implement without any essential reduction of accuracy (Baltsavias & Stallmann, 1992).

The use of polynomials, requires no need for interior or exterior orientation of the images and any other special image characteristics which can cause geometric distortions are directly included in the mapping. Further more, there is no need for detailed or in fact any knowledge of the image geometry, at the cost of additional (more than six) well distributed and accurately measured GCPs and CPs (check points).

Two pairs of polynomials are used by the proposed model as shown below:

$$\begin{aligned} x'' &= Fx(x', y', h) = Tx * Cx \\ y'' &= Fy(x', y', h) = Ty * Cy \end{aligned} \quad (1)$$

$$\begin{aligned} X &= Gx(x', y', h) = Vx * Px \\ Y &= Gy(x', y', h) = Vy * Py \end{aligned} \quad (2)$$

where x' , y' , x'' and y'' are the image coordinates of left and right image respectively, of a ground point with model coordinates X , Y and height h . Tx , Ty , Vx and Vy are the term vectors and Cx , Cy , Px and Py are the parameter vectors (term coefficients).

The polynomial functions Fx and Fy effectively perform an image-to-image registration when the ground height is known. Similarly, the functions Gx and Gy perform an image-to-model (image-to-ground) registration. In other words, polynomial functions of (1) perform an image space transformation and polynomials (2) an object space transformation (see Figure 1). The height h is an independent variable that connects the two transformations. The coefficient vectors can be calculated by least squares when sufficient GCP data is available.

The type of the polynomials (order and terms) mainly depends on the type of the images under consideration. For example, when the stereo pair follows the frame geometry the polynomial form is expected to be simpler compared to

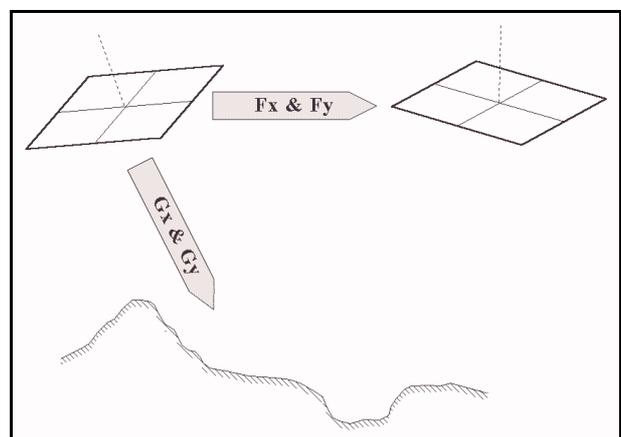


Figure 1. Schematic image-to-image and image-to-object transformation as simulated by the polynomial mapping functions of the proposed model

that of a SPOT stereo pair where every scan line has its own perspective center. The same applies when only a small section of the overlap area is under consideration. Furthermore, the type of the polynomials might be influenced by other parameters, e.g. the general shape of the ground imaged by the stereo pair, the location in the overlap area of the small section under study, the accuracy and distribution of the GCPs and CPs used, etc. This difficulty to determine the exact type of the polynomials may be one of the several reasons that the polynomial mapping functions have never been of real interest in the photogrammetric scientific field.

Usually the determination of the actual form of the polynomials is through a suitable mathematical analysis of their term coefficients. For example, starting from the full form of a specific order, say 3rd, coefficient variance and covariance may be calculated using GCP data. Based on this information, terms that don't have a major contribution to the actual solution may be identified and removed. Unfortunately, even this simple analysis requires certain thresholds to be used which complicates the problem and introduces additional uncertainties. Another problem that arises with this method is that because of their nature there is a tendency for the polynomials produced to fit well only on the GCP data used to calculate them.

In the proposed model, the determination of the polynomial form is based purely on the available CP data. This way, the tendency for a very good fit to GCP data is eliminated and a more general solution is provided. Since interpolation errors are generally smaller than extrapolation errors, for best results, a suitable number of the GCPs used must be located near the perimeter of the area of interest. The CPs must have a well distribution through out the area of interest.

The order and actual terms of the polynomials is automatically determined using the root mean square error (RMSE) of the CPs. Starting from the full form of the polynomial for a specific order, the RMSE of the CP data is calculated. All terms of the polynomial are removed in turn and the RMSE of the CP data is calculated and recorded each time. The term that produces the highest reduction of the RMSE gets totally removed. This trial and error process continues with the remaining terms of the polynomial until no further reduction of the RMSE is observed. Each time the coefficients of the polynomials are calculated by least squares from the available GCP data.

At this point must be noted that polynomial mapping functions other than (1) and (2) can also be used to model the image and ground geometry. For example, a function $H_z(x, y, x', y')$ can be defined to obtain the ground height h when the image coordinates of homologous points is known. Similar functions H_x and H_y can be used for obtaining the planimetric ground coordinates. The combinations are many and the actual choice of specific functions depends mainly on the follow-up processing required.

2.2 Image Matching

Although an accurate image matching algorithm could be applied, in the current state and for testing purposes, the proposed model uses a very simple matching technique. This was partly imposed by the requirement for a fast solution to the problem and partly by the choice of the polynomials (1) and (2). The purpose of image matching is the calculation of the independent variable i.e. the height h , for every pixel of the reference image (left). This is achieved using the image-to-image polynomial pair (1). Since h is an unknown, the matching algorithm has to calculate its value by trial-and-error. Cross-correlation is used to measure the validity of each trial.

For every possible value of the height (between a minimum and a maximum, using a height step) the image coordinates of the corresponding points in the search image are calculated by the image-to-image polynomials. The cross-correlation coefficient of the calculated candidate homologous points is determined and the highest is chosen. The choice of the highest correlation coefficient determines in fact the height value that used to calculate the location of the corresponding candidate homologous point.

Using this approach, the searching of homologous points is done on the epipolar line as it is approximated by the image-to-image polynomials. This reduces the search space and the calculation cycle is quite fast especially if an appropriate height step value is chosen (close to twice the expected height accuracy). Furthermore, the image geometry is taken fully into account during the matching process. The matching is virtually guided by the geometry and not the pixel intensities. The later are only used to confirm or not the geometric calculations. This reduces the possibility for false matches, which is expected to be high since a very simple matching algorithm is used.

The above technique looks similar to the vertical-line-locus (Krupnik & Schenk, 1994), but it has a couple of major differences. First, instead of the ground planimetric coordinates, the image coordinates are kept fixed. This is why the search lines produced are the epipolar and not the radial lines from the nadir. Second, the value of the ground height is varied, instead of the corresponding image coordinates on the two images of the stereo pair. This has the advantage of directly obtaining the height value and reduces the calculation cycle of the cross-correlation coefficient since the image

coordinates on the left image are kept fixed. In practice, certain parameters can be adjusted in order to increase computational speed and reduce false matches e.g. definition of a suitable correlation coefficient threshold, local redefinition of maximum and minimum height values depending on the height values of neighbouring points, etc. (Papapanagiotu & Hatzopoulos, 1997).

2.3 Erroneous Height Removal

Since there is no internal quality measure of the matching process except for a minimum acceptable value for the correlation coefficient, there are some erroneous calculations of the ground height. These errors are caused by false matches and blunders. Although it has not been tested as such, taking into account the matching technique that is used, in the general case, these errors cannot be systematic but rather random. The majority of these can be easily identified solely by visual inspection of the heights produced.

The proposed model includes two simple criteria namely "height" and "population" which can be used to automatically remove the vast majority of these wrong matches after the elevation extraction process is completed. The criteria are based on the assumption that neighbouring points should not have large height differences. Using this assumption homogenous regions are identified in the reference image. In this context, homogenous regions or just regions are image areas that no point they contain has a height difference larger than a specified threshold from at least one of its close neighbours belonging to the same region. The goal is to obtain a large region covering almost all the reference image with many small ones in between which are identified as erroneous areas. This can be achieved by having a relatively low correlation coefficient threshold during the matching process. This way, as many as possible reference image points are matched. This also produces more heights that are erroneous but they can be safely removed by the above criteria.

The height threshold that is used to identify the homogenous regions is closely related to the expected slope of the terrain. For the definition of its value the pixel size on the ground must be taken into account together with the height accuracy of the matching process i.e. the height step used. The experience has shown that when the planimetric pixel size is less than the height step (usually the case), a height threshold around twice of the height step value is sufficient. This translates to a slope value of 33%. When the pixel size approaches the height step, a larger value must be defined and when it is much smaller, a value close to the height step is more realistic.

2.3.1 Height Criterion: It compares the population levels (number of points) in adjacent regions. The region that has the smaller population is removed. This explains the requirement for a main large region, which is identified as the correct one, when the other smaller ones in between are identified by the height criterion as erroneous and are automatically removed. The height criterion effectively removes reference image areas where the elevations calculated are extremely different to the general surrounding area.

2.3.2 Population Criterion: The height criterion cannot be applied in regions where no adjacent ones exist. These cases exist in image areas where the lack of pixel contrast causes the matching process to fail e.g. sea cover. In most cases, these regions are erroneous and must be removed. This is done by the population criterion, which removes any region with a population level less than a certain threshold. This level is usually very low (a few hundred pixels compared to tens or hundreds thousands of pixels of normal regions) and can be easily determined by a simple visual inspection of the heights calculated by the matching process. Since population levels alone are no good quality measures for region removal there is a high possibility for some correctly calculated heights to be cleared together with the erroneous ones. The practice has shown that the percentage of these points is very low and doesn't effect the general performance of the population criterion.

2.4 Ground Coordinate Calculation

The image matching process produces the corresponding ground height for the reference image pixels. The planimetric coordinates of ground i.e. X and Y, are calculated by the image-to-model polynomials (2). The process is straightforward since all variables involved are known and is applied after the image matching and region exclusion process complete. If a regularly structured model of the terrain is required, it can be produced in a later stage using a suitable interpolation algorithm.

3 TEST RESULTS AND DISCUSSION

3.1 Test Sites

In order to test the validity of the proposed model, a cloud-free panchromatic digital SPOT stereo pair of Lesvos Island

Terrain Characteristic	Loutra	Apothika	Kardama
Minimum Height	0 m	0 m	24 m
Maximum Height	546 m	615 m (approx.)	515 m
Average Height	150 m	251 m	221 m
Minimum Slope	0 %	0 %	0 %
Maximum Slope	194 %	160 %	178 %
Average Slope	29 %	25 %	20 %
Existence of Coast Line	Yes	Yes	No
Sea Cover (approx.)	29 %	13 %	0 %
Land Area (approx.)	4,000 sq. km	6,100 sq. km	730 sq. km
Land Cover	Heavy Vegetation of Pine and Olive Trees	Rocky Outcrops, Grasslands, some Olive and Oak Trees	Rocky Outcrops, Grasslands
Stereo Pair Characteristic			
Image Size (Columns x Rows)	Left: 837 x 577 Right: 895 x 605	Left: 801 x 931 Right: 892 x 1010	Left: 2021 x 2873 Right: 2269 x 2877
Scale (approx.)	1:824,000	1:824,000	1:18,300
Ground Overlap Size (approx.)	9.0 x 6.2 km	8.5 x 9.2 km	3.2 x 2.3 km
Pixel Size on Ground (approx.)	10.7 m	10.7 m	1.2 m

Table 1. Characteristics of terrain and image stereo pairs of the three test cases

(Greece-Hellas) was obtained. For practical purposes, subsequent tests were made on only two small parts of the overlap area. This also gave the chance to study the behaviour of the proposed model under two entirely different ground cover types observed in the island that are known to influence the accuracy of image matching. The first test site, Loutra, has steep slopes and heavy vegetation (see Table 1). The expected height accuracy that can be obtained for this type of area is 15-20 meters (Trinder et. al., 1994). The second, Apothika, has medium to steep slopes and very little vegetation (see Table 1). The expected height accuracy for this test site is 10 to 15 meters.

In order to test the generality of the proposed model a third test site was chosen. This area, Kardama, is located in the middle-east side of the Apothika test site and as such has similar ground cover, but the slopes are smoother (see Table 1). A stereo pair of aerial photographs on diapositive were obtained. The photographs were digitised by an ordinary A4 DTP scanner (Mustek 1200SP) with 1200 dpi resolution. Only the overlap area of the photographs could be imaged since, because of size difference, the rest of the photographs was lying on the scanner frame which was located higher around the scanner's glass plate. The imaged part of the photographs was forced flat with the aid of a glass plate. Because of memory limitations, the original scanned overlap area of the photographs (more than 90 MB each) were degraded down to 400 dpi. For practical reasons, only a large part of the overlap area was used in the subsequent tests.

3.2 Ground Point Data

For the three test sites, 14 map sheets of scale 1:5,000 were used to collect real ground point data. The map sheets were digitised at 200 dpi and using the given tic point data they were georeferenced with an accuracy of about 2m or better. Planimetric and height data for a suitable number of points recorded from the digitised map sheets. Then, the ground points were identified in both images of the three stereo pairs and their image coordinates (column and row) were recorded. Based on their good distribution, a sufficient number of them were selected as GCPs and the rest were used as CPs, for each test site.

3.3 Polynomial Definition

The identified GCPs and CPs were used to automatically calculate the terms and coefficients of the corresponding image-to-image and image-to-ground polynomials, as described in section 2.1. The automatic polynomial definition was started from the full second order form and it

Polynomial Details		Loutra	Apothika	Kardama
GCPs		29	27	26
CPs		73	52	34
Image-to-Image Polynomials	Column Terms	6	9	8
	Row Terms	6	7	7
	Additions	12	16	15
	Products	15	21	18
	Powers	4	3	4
	GCP Column RMSE (pixels)	0.56	0.22	1.13
	GCP Row RMSE (pixels)	0.58	0.23	0.46
Image-to-Model Polynomials	CP Column RMSE (pixels)	0.81	0.32	1.22
	CP Row RMSE (pixels)	0.52	0.26	0.71
	CP Column RMSE (pixels)	0.43	0.22	0.71
	CP Row RMSE (pixels)	0.68	0.34	1.00
	Column Terms	7	7	9
	Row Terms	9	9	9
	GCP X RMSE (meters)	2.29	5.79	1.65
GCP Y RMSE (meters)	2.94	1.75	1.21	
GCP Total RMSE (meters)	3.73	6.05	2.04	
CP X RMSE (meters)	3.81	4.90	2.14	
CP Y RMSE (meters)	2.92	2.54	1.67	
CP Total RMSE (meters)	4.79	5.52	2.71	

Table 2. Image-to-image and image-to-model polynomial fitting details for the three test cases

completed in a couple of seconds. When started from the full third order no significant accuracy improvement was obtained and the number of terms were double in number in almost all cases. The obtained RMSE (see Table 2) for the GCPs and CPs was in the expected range or better indicating that the use of polynomials is a good approximation of the individual underlying stereo geometry. This is true in all cases except for Kardama (especially the GCPs column RMSE) which is above the expected accuracy (0.5 pixels). This is due to the low accuracy of the digital map sheet used (about 2m), compared to the accuracy that can be obtained from the digitised aerial photographs (pixel size about 1.2m).

3.4 Image Matching

The matching process was carried out using an ordinary IBM-compatible personal computer (see Table 3). For all test cases a correlation threshold of 0.5 was used. This low value was chosen so that an increased number of matched points can be obtained taken into account that the stereo images had no radiometric enhancement and a relatively large correlation window was used (9x9). The range of possible heights was close to the maximum and minimum ground heights of the site as identified from the corresponding map sheets. The height step used corresponds to the theoretical accuracy that can be obtained i.e. 10m for the SPOT images and 2m for the aerial photographs (height accuracy of 1:5,000 scale map).

The number of available points for matching is not equal to the total number of image points. This is because the image border (width of 4 pixels) is not used during the matching process due to the requirement for the correlation window to be completely inside the image area. The number of image points matched was very high reaching 85-90% for the two SPOT cases and 48% for Kardama. This is true when taken into account the sea cover of the SPOT images and the large radiometrically uniform areas of Kardama test site where most points cannot be matched.

The matching process was quite fast. It depends mainly on the total number of the different candidate heights that have to be checked, which is equal to the range of possible heights divided by the height step. This is true although the image-to-image polynomials used in each individual test case vary somehow in computational complexity.

3.5 Region Exclusion

The height data obtained from the matching process was cleared from erroneous matches by applying the two criteria describe in section 2.3 (see Table 4). In all test cases, a height difference threshold about 1.5 times of the height step is used. This value ensured one large region for the two SPOT test sites. This was not possible for the Kardama test site due to the large radiometrically-uniform areas of the stereo pair. These were caused by grasslands where erroneous height data appears in small clusters (tens of pixels in size) together with small clusters of correctly calculated heights (because of local features e.g. rocks or trees). In this case, the application of the population criterion removed some correct heights together with the erroneous ones. This also explains the low percentage of height data that remained (48.15%) i.e. areas where the existence of suitable contrast allowed correct matching.

Parameter	Loutra	Apothika	Kardama
Minimum Height (meters)	0	0	20
Maximum Height (meters)	600	600	520
Height Step (meters)	20	20	4
Correlation Window Size (pixels)	9 x 9	9 x 9	9 x 9
Correlation Coefficient Threshold	0.5	0.5	0.5
Use of Neighbor Heights	Yes	Yes	Yes
Characteristics			
Matching Speed (pixels/sec)	2,059.05	2,245.21	417.01
Matching Time (h:mm:ss)	0:03:08	0:05:26	3:50:30
Total Number of Points	482,949	745,731	5,806,333
Number of Points Available for Matching	471,702 97.7 %	731,939 98.2 %	5,767,245 99.3 %
Number of Points Matched Successfully	367,947 76.2 %	655,210 87.9 %	4,285,561 73.8 %

Table 3. Image matching parameters and performance when a Pentium II 266MHz with 64MB RAM running Win95 was used

Parameters	Loutra	Apothika	Kardama
Neighbour Search Distance (pixels)	2	2	2
Height Difference Threshold (meters)	30	30	6
Population Threshold (pixels)	1000	350	200
Results			
Processing Speed (pixels/sec)	62,316	57,364	4,712
Processing Time (h:mm:ss)	0:00:31	0:00:52	1:22:09
Number of Homogenous Regions Identified	8,250	9,184	279,215
Number of Homogenous Regions Removed by Criteria	8,249 99.99%	9,182 99.98%	278,942 99.90 %
Number of Points Removed by Criteria	94,201 19.51%	65,283 8.75%	1,489,781 25.66%
Number of Homogenous Regions Remained	1 0.01%	2 0.02%	273 0.10%
Number of Points Remained	273,746 56.68%	589,927 79.11 %	2,795,780 48.15%

Table 4. Erroneous heights removal process parameters and results using the height and population criteria

The value of the population threshold was defined after visual inspection of the height data obtained from the matching process. The value of 1000 used for the Loutra test site was imposed by a large concentration of erroneous heights located in the sea cover. The same applies for the Apothika test site where the concentration was smaller. For the Kardama test site the value of 200 was chosen so that all the small clusters of erroneous heights observed in the radiometrically-uniform image areas can be successfully removed. For all test cases the automatic removal of the erroneous heights performed quite satisfactory in almost all situations. The only instance that the two criteria were unsuccessful was on some parts of the coastline (mainly the east and south-east). This is believed that happened because the sun reflections on the shallow waters of one image were misinterpreted by the matching algorithm as road reflections which is located next to the coastline and runs parallel with it.

3.6 DTM Comparison

A regular grid of real heights (DTM) was build using digitised contour data and inverse distance interpolation. The contour data was collected from 1:5,000 scale maps, the same ones used to obtain the GCP and CP data. For the two SPOT and Kardama test sites, the 20m and 4m contour lines were digitised, respectively. The cell size of the corresponding DTMs built, was 10m and 2m for the SPOT and Kardama test sites, respectively.

Using the image-to-model polynomials, the height data obtained from the matching process, after automatically clearing the erroneous heights, were transferred in regular grid format. This grid was made equal in cell size and length with the corresponding one of real heights. Grid nodes that corresponded to reference image points that could not be successfully matched or image points with calculated height that was removed by the application of the height and population criteria, had their height marked as unknown. In cases where two or more reference image point heights corresponded to one grid node, the average of the heights was assigned to that node.

The image extracted and real DTMs were statistically compared (see Table 5). The obtained RMSE in all cases were inside the expected range indicating that the accuracy of the height data which is automatically extracted from the stereo images using the proposed model, follows the theoretical values. This is especially true for the two SPOT test cases. For the Kardama test site, the RMSE obtained is higher by 60cm from the theoretical value (2m i.e. half of the digitised contour interval of the 1:5,000 scale map). This is believed that happened because of features like stone fences between grass-fields, piles of rocks, trees, bushes, etc., which are included in the DTM of the proposed model but not in the DTM created by the map. The value of -6.5m of the average height difference of Loutra test site indicates that the DTM created by the proposed model has elevation values higher by about 6m compared to real ground heights obtained by the map. This is believed that is caused mainly by the heavy vegetation of the area, especially the existence of high full-grown olive trees.

Comparison Results	Loutra	Apothika	Kardama
Maximum Positive Height Difference	150 m	132 m	54 m
Maximum Negative Height Difference	-240 m	-129 m	-96 m
Height Difference Average	-6.48 m	0.66 m	0.23 m
Absolute Height Difference Average	11.23 m	8.21 m	1.83 m
Root Mean Square Error	16.74 m	11.25 m	2.60 m

Table 5. Comparison results of image extracted and real height DTM data

4 CONCLUSIONS

The test case results indicate that polynomials can be safely used to replace the actual photogrammetric equations that describe the geometric relations of digital stereo pairs. This is extremely useful if only a section of the overlap area is available where it is very difficult the application of the pure photogrammetric techniques since there is no information for the location of perspective center. The use of polynomials, as approached by the proposed model, is also suitable for dealing with the problem of 3D model coordinate extraction offering an automatic fast solution without loss of accuracy. This is especially true if it is taken under consideration that, a very simple matching technique is applied with limited accuracy (half a pixel) without any kind of radiometric or other enhancement of the digital images. The proposed model was successfully applied without any modification to two extremely geometrically complicated cases i.e. multiple principal points of SPOT images and unstable DTP scanning geometry. This sets the grounds for a uniform and general solution to almost any photogrammetric problem. The accuracy of the 3D model coordinates obtained follow the theoretical values and the extraction percentage was very high compared to the available usable image area. These characteristics make the proposed model suitable for personal computers since there is no special hardware requirement.

The main disadvantage of the proposed model and the use of polynomial mapping functions in general, is the requirement for an increased number of GCP and CP data which is hard to obtain. This can be partly solved by elementary geometric correction of the digital stereo pair before the polynomial determination. This way the polynomials will be simpler (less terms and smaller order) and the number of required ground points will be reduced. On the other hand, strict models can be applied for the collection of the increased number of GCPs and the subsequent processing can be performed using the proposed model so that high computational speeds can be achieved.

The proposed model has already been transferred into software (GACCM 3.11) with a user friendly "window like" interface running to a variety of operating systems. Although the software is in a prototype stage and some technical parts of it are still under development (mainly performance issues), the test cases presented here were fully processed by it. The proposed model can be further enhanced. The contrast improvement of the digital images e.g. Wallis filter, and a robust matching algorithm with sub-pixel accuracy - like least squares matching - is believed that will improve the accuracy levels of the model. Better or enhancement of the erroneous height determination criteria can also be under consideration towards a more accurate solution.

A study of the polynomial mappings used by the proposed model, on MOMS-2P and SPOT stereo imagery is under way, and the results are going to be published soon. At the same time, the use of polynomial neural networks like GMDH are researched. Near plans include the application of the model to a variety of digital imagery e.g. photographs from metric and non-metric cameras, as well as to extremely difficult photogrammetric problems like the mapping of sea waves caused by surface winds.

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