How to Create a Virtual Mountain with a Map, Compass and Camera

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Abstract

Archaeologists mostly have very specific requirements when interested in digital terrain models. Niche solutions are in demand when common ways and means do not meet these requirements. The vectorization of contour lines in paper maps is a proven method of data acquisition. Terrestrial stereophotogrammetry is another method that provides a huge amount of up-to-date data. Moreover, it reduces the time of necessary fieldwork to a minimum. The present paper explains how to combine these two methods for a digital terrain model.

***Key words**: digital terrain model, terrestrial stereophotogrammetry*

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1 Introduction

The city wall of the ancient Messene in Greece is located at the distinctive mountain Ithome and is one of the best preserved fortifications in the Mediterranean region. The archaeological research is supervised by members of the Free University of Berlin and the Society of Messenian Archaelogical Studies. The results will be presented in a digital terrain model (DTM). Furthermore, there will be some possibilities of research with this model like the visibility analysis.

This kind of DTM has very specific requirements resulting from spatial extension, accuracy needs and a restricted time budget for the fieldwork. The accuracy can vary within the DTM. Miscellaneous methods of data acquisition are used to meet these requirements. The concise definition of a reference coordinate system is a vital condition to establish a consistent data processing chain. Thus every dataset can be spatially oriented within this reference coordinate system. It is important to verify the orientation after each processing step.

In this case, two kinds of base data are used. First, 1:5,000 scale maps on paper with 4 m equidistant contour lines, second, terrestrial stereo photographs. The map data is transformed to the reference coordinate system, the Greek HATT[1] system, using control points measured by GPS. The relation of the photogrammetric data to the reference HATT system is known by artificial control points established in the field. In the end an AUTOCAD dxf file is generated that contains the elevation data. As the amount of data is relatively big, two different arrangement methods of the terrain points are used to get an expedient data format for easy data exchange and to save the cost of computation.

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[1] Cliff Mugnier, “Grids & Datums – The Hellenic Republic,” *Journal of the American Society for Photogrammetry & Remote Sensing* 68 (2002):1237.

2 DTM Derived from the Map

The derivation of a DTM by vectorizing contour lines is well-known by decades and will be outlined briefly in this paper. The scanned maps are equalized by using the coordinate crosses to eliminate the distortion caused by the paper (expansion, shrinking) and the scanning process. The crosses are printed on the maps in a 500 m pattern (see fig. 1).

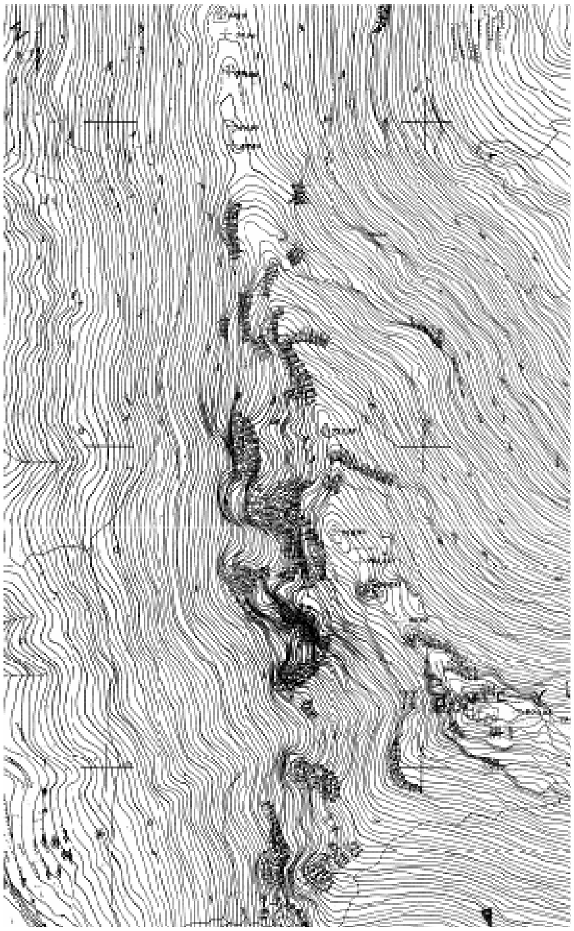

Figure 1. Part of the map.

The manual vectorization of the contour lines, elevation points, form lines and control points is performed in a random coordinate system. Hence, the vector data must be transformed to the reference coordinate system. This transformation is done by using identical points which are observable in the map and measured by GPS in the field to get a HATT coordinate. In the next step, the DTM is generated by using the software SCOP++ from INPHO. The calculation is done by an elevation interpolation of 5 m spaced grid points. This grid data format has the advantage of a faster representation in AUTOCAD compared to a mesh of triangles. The precision of a DTM derived from a map essentially depends on the map's accuracy. The accuracy information of the map is unknown, but on the strength of past experience the position accuracy is estimated to 1 m (σ) and the elevation accuracy to 0.3 m (σ).

The illustration of the terrain shape by contour lines reaches its limits, where the terrain gets steep or the contour lines are painted over by signatures. The contour lines are upon each other and form big, black spots with other signatures respectively. A vectorization of these contour lines will not reproduce the terrain shape with the proper accuracy. The DTM precision in this area will be less than in the remaining model. As some parts of the ancient wall are supposed to be in this area, a low precision cannot be accepted. A new survey of this area, the western steep slope of the mountain Ithome, is necessary. The method of terrestrial stereophotogrammetry is chosen for this task, as it has the opportunity of getting a huge amount of data within a short period of time. This part of the model derived from the map will be replaced by the new photogrammetric data.

3 Field Work

Ground control points are established and measured by GPS in the HATT system for the exterior orientation of the images. The control point signal dimension is adapted to the image scale and is about 1.5 m² big (see fig. 2).

Figure 2. Measuring a control point signal.

A calibrated digital camera Nikon D200 with a focal length of 105 mm is available for this work. The on-site investigation yields the result of a nearly straight line of possible camera positions 1,200 m away and parallel to the slope. In this distance the area of interest is covered by a strip of 17 images with an overlapping of more than 50 %. The achievable spatial accuracy of this configuration in the stereoscopic processing has its worst component in the camera direction and can be estimated with the following formula.

$$\sigma_Z = \frac{Z^2}{c_k \cdot B} \cdot \sigma_B$$

Z = Distance to the object (1,200 m)
c_k = Focal length (105 mm)
B = Distance between two camera positions (approx. 70 m)
σ_B = Image measurement accuracy (2 µm)

On the strength of past experience the image measurement accuracy is a third of a pixel size on the sensor. The Nikon D200 has 6 µm pixels. The estimated spatial accuracy in the camera direction σ_Z is about 0.4 m.

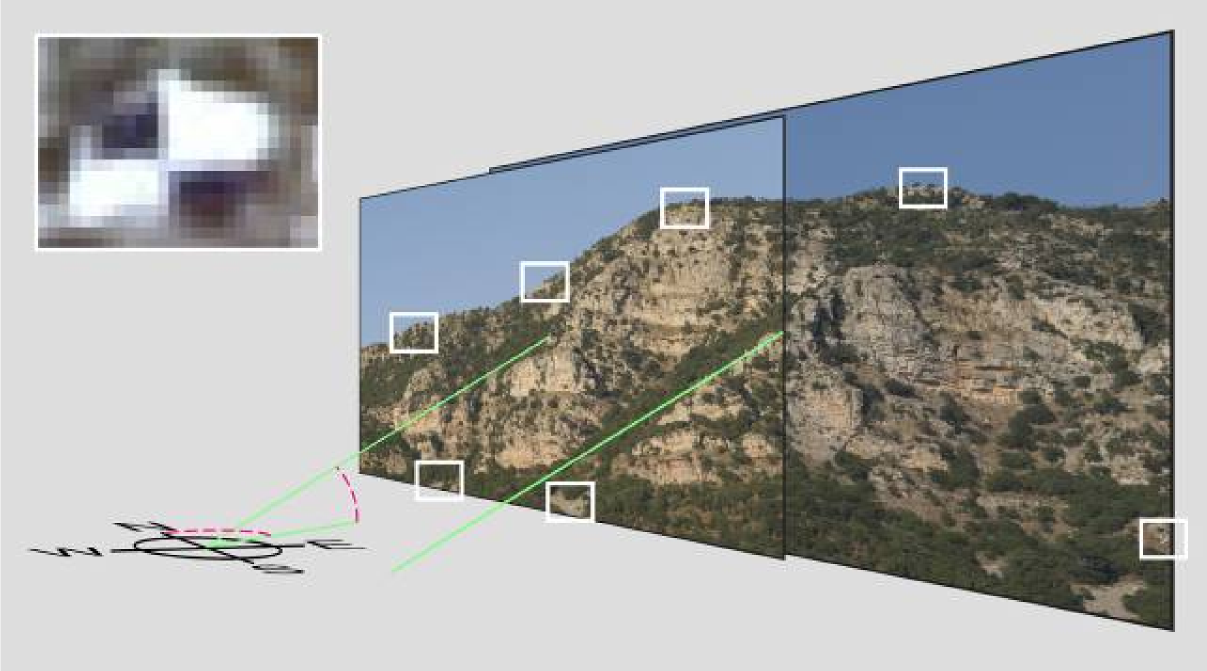

Figure 3. Image pair with camera directions and control points.

The camera positions are found with the help of a handheld GPS receiver to ensure the straightness of the camera line and the distance from one camera position to the next. Stereophotogrammetry requires parallel camera directions. The azimuth and zenith angles are defined with the first photo and measured by bearing the direction with a compass and clinometer. For the following photos, the mountain is aimed at with the compass and clinometer, the aimed point is kept in mind and aimed at again with the camera. Then the photo is taken (see fig. 3). With this very simple method the parallelism of the directions is ensured with a standard deviation (σ) of ± 1 degree.

The mountain extends from north to south. The western slope which is the area of interest is well illuminated by the sun only in the evening. The illumination situation changes quickly due to the setting sun. Hence, there is little time in the evening to get a few good images. Different illumination situations have an impact on the location of hard shadows in the images and cause blunders in the processing. Furthermore, the stereoscopic impression in an image pair is diminished by an altered illumination situation.

4 Photogrammetric Processing

As a preprocessing step the images are radiometrically adjusted to each other to ensure a proper stereo impression. The photogrammetric processing is done with the software LPS from ERDAS developed for aerial and satellite imagery. To cover the task of terrestrial imagery, the coordinate system of the control points has to be rotated to simulate the aerial case. Therefore, starting from a known position (RI03) with a given coordinate (see fig. 4), the camera direction is reconstructed with the azimuth and zenith angle known from the compass and clinometer. The perpendicular is dropped from a second known position (PP08) to the camera direction. Then the intersection is calculated. These two axes completed with the orthogonal complement as the third axis represent a coordinate system for an aerial image strip. This is only temporarily valid for the image processing. In order to establish the control point transformation three pairs of identical points are needed in the HATT system and the aerial system. The HATT coordinates of RI03 and PP08 are measured by GPS in the field. The origin of the aerial system is calculated in the HATT system and has the random aerial coordinates X = 1,000 m, Y = 1,000 m, Z = 1,000 m. The aerial coordinates of PP08 and RI03 are easily calculated by their distance to the origin. This set of identical points allows the transformation.

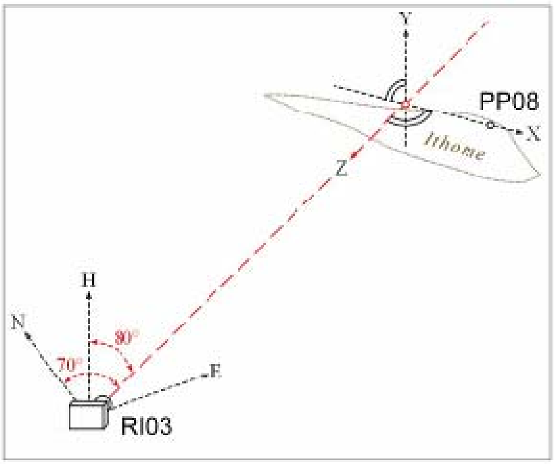

Figure 4. Construction of an aerial coordinate system.

The following step of the exterior orientation in LPS succeeds without any difficulties by the use of these modified control points and the tie points automatically detected by the program. The oriented image strip with its control points (big rectangles) and tie points (small rectangles) is shown in fig. 5. After this step the LPS module ATE is used for the automatic detection of ground points based on the method of image correlation. 160,000 points are found. The mathematic accuracy of these points is about 1 to 2 cm (σ), but most of them are on the vegetation and therefore not usable for the DTM. Additionally there are blunder points caused by the different position of hard shadows mentioned before. These points have to be removed by manual operations using a stereo monitor together with the LPS module Terrain Editor. After this work, there is a cloud of 56,000 points remaining. These points have an average spacing of about 80 cm, so it is very clear that the accuracy of terrain modeling at rough surfaces is about 10 to 20 times worse than the mathematical calculation of a single point.

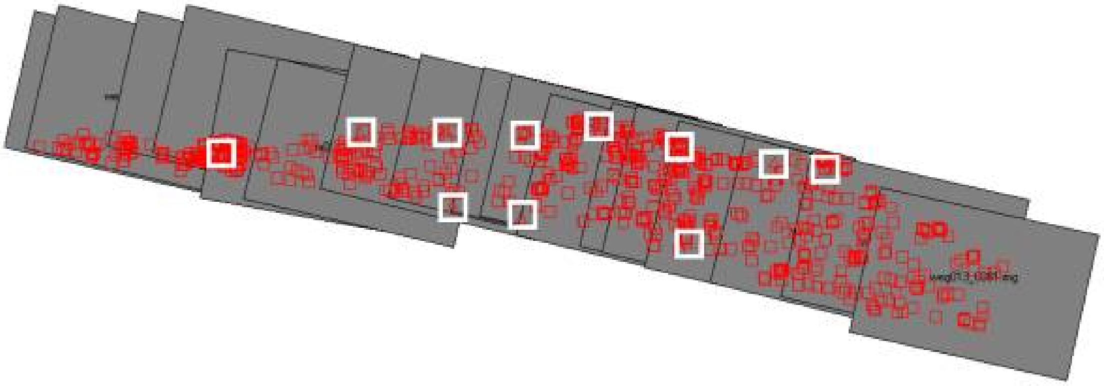

Figure 5. Oriented image strip with control and tie points.

The remaining point cloud is transformed back to the HATT system using the same identical points as before. After this step a further processing with LPS is not possible. The slope contains parts with overhanging rocks, so that one position coordinate might have several elevations. But this situation is very typical of laser scanning applications.

5 Combination of Different Data Streams

The laser scanning software Leica CYCLONE is used for the next processing step. CYCLONE is an easy to handle tool for the manipulation of point clouds. At first the grid points of the map derived DTM are imported to the program and a surface is calculated. Next it has to be verified that the image derived points do not have any constant elevation steps. Therefore the point cloud is imported to CYCLONE. The new points are expected to provide new information about the terrain surface. However the boundaries of the cloud have to fit to the existing surface. This is verified for the whole model. Now the grid points are cut out where image derived points are existing. The adaptation of a surface to such a combined point cloud does not work with CYCLONE. CYCLONE tries to make a triangulated mesh of the points. This needs a consistent point orientation in the view of the Z axis. The grid points have a regular grid in the view of the Z axis, but the image points have an irregular arrangement in the view of the camera direction. For the step of a surface calculation a different method is needed. This can be realized with the software RAPIDFORM. This tool adapts a mesh of regular triangles to the point cloud. Afterwards the mesh is thinned out to reduce the amount of stored data but the high mesh density is retained in terrain parts with a high curvature.

The data format of a triangulated mesh has the disadvantage of a high computer requirement using the software AUTOCAD in a 3D view. Therefore only the terrain part with the image data is stored as a triangulated mesh. The surrounding area is stored as a grid data format to save the cost of computation. The combination in the 3D model is managed by a small overlapping area between these two data formats. The grid points are the base data for the mesh calculation in RAPIDFORM. This assures that there are no gaps in the model in this area. The entire model with an extension of 3 km by 3 km is shown in fig. 6.

6 Summary

This paper presents one possibility of a DTM generation under specific circumstances. The requirements of time consumption in the field, spatial extension and accuracy are met by a meaningful combination of two different data acquisition methods, vectorization of contour lines and terrestrial stereophotogrammetry. The outstanding achievements of this work are the down-to-earth solutions during the processing steps like the use of very simple equipment (compass, clinometer) for the orientation of a standard digital camera, bed sheets as control point signals and the modification of data to utilize standard software for the calculation.

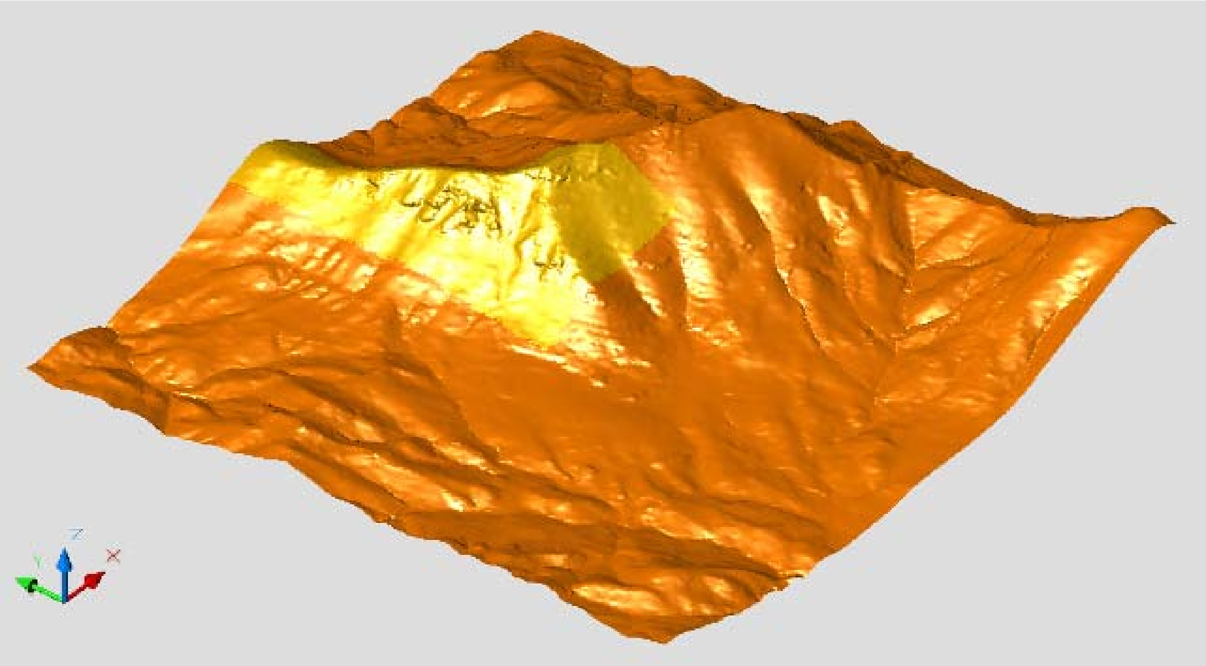

Figure 6. View of the DTM with the image derived part (bright-toned) and the surrounding map derived part.

Bibliography

Cliff Mugnier, "Grids & Datums – The Hellenic Republic," *Journal of the American Society for Photogrammetry & Remote Sensing* 68 (2002):1237.