HUN_DEM, the high resolution digital elevation model for Hungary

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1. Introduction

Within the frame of the European Harmonisation Program of the Ministry of Agriculture and Rural Developments, three nation-wide connected projects were launched by the Institute of Geodesy, Cartography and Remote Sensing (FÖMI) in 2000 to be carried out during 3 years. These are the following: a.)"Wall to wall Aerial Photography of Hungary"; b.) Creation of a 5m x 5m high resolution DEM of Hungary; c.) Set-up of Full Digital Orthophoto Coverage of Hungary (MADOP).

The above mentioned projects were only the main steps of implementation, but there were other minor projects which provided the successfulness of the majors. This paper concentrate only to the high resolution DEM (creation, procedures, quality check), but we have to take into consideration that the new DEM would not be completed without the two major twin and minor projects.

2. The two twin projects

2.1. Wall to wall Aerial Photography of Hungary

In 2000, within the frame of the European Harmonisation Program of the Ministry of Agriculture and Rural Developments, was decided Hungary needed a whole coverage of the country by aerial photographs. After a comparative analysis of the different solutions the 1:30 000 scale aerial survey was decided. (see table 1.)

Scale of the aerial survey	Number of photographs (pcs)	Duration of the aerial survey (incl. turns) in hours	Ground resolution of the aerial photographs (in cm)	Scanning 21µm: one picture is 375 MB
1:10 000	58 812	192	8 - 12	22,1 TB
1:20 000	14 732	96	20 - 25	5,5 TB
1:25 000	9338	77	25 - 32	3,5 TB
1:30 000	**6591**	**65**	**30 - 36**	**2,5 TB**

Table 1: Aerial mission planning data for decision-making [1]

The project was carried out within three months by Eurosense Hungary Ltd.. All the taken photographs was checked by a very strict quality check (executed by FÖMI) and scanned by 21µ resolution. So the original photographs ground resolution in digital form is approx. 63 cm.

Table 2. shows the number of photographs archived by FÖMI:

	Number of repetitions				All projec tion centre	Digital images pcs	Colour slides pcs
	1^x	2^x	3^x	4^x			
Number of projection centres	5884	719	32	7	**6642**		
Including repetitions	5884	1438	96	28			7446
Handed over to FÖMI						**6667**	**7446**

Table 2.: Number of photographs archived by FÖMI [1]

2.1.1. Aerial triangulation of Photographs

The development of the fourth order geodetic triangulation network of Hungary started in mid seventies and was finished by 1992. In accordance with the specifications, the density of the fourth order points is 1 point/2 km^2 in rural areas, while denser in the built-up areas, i.e. less than 1 point/1 km^2. The accuracy of the fourth order network is very good: ± 3-4 cm and about 10 cm in Z. The network is built on the points of the higher order triangulation network, so it forms *a countrywide uniform geometric basis and also could serve for quality checking of HUN_DEM.*

When realizing MADOP, it was advisable to match the blocks of aerotriangulations to those points. The accuracy of the fourth order points is much better than the accuracy values, which can be achieved from aerial images at scale 1:30 000, so they serve as a reliable basis for geometric matching of the aerial triangulation blocks. As a result of the aerotriangulation block adjustment, we have got the orientation parameters of the individual aerial photographs, which enable us to fit the aerial photographs into the national geodetic control network within the error limit of the aerial triangulation. The accuracy of the orientation parameters of the aerial photographs and the reliability of the DEM together will determine the accuracy of the digital orthoimages to be produced, i.e. the accuracy of the matching into the national geodetic control network. [1]

The fourth order points stabilized in the field by concrete panels are hardly identifiable on the aerial photographs without preliminary marking in the field. But using a specific aerialtriangulation measuring procedure, considering the given technical conditions, we managed to reach that the digital orthophotos match each other in a countrywide uniform geometric order, thanks to having used the fourth order points as control points identified and measured in corresponding quantity.
From 2001 to 2003, we have performed the aerotriangulation more (due to the overlapping aerial triangulation blocks), than of 6 667 aerial photographs covering the territory of the whole country, at the beginning by using original colour slides and analytic method (CartoHansa), later on by digital procedure based on raster aerial photos (Eurosense). [1]

Aerial triangulation procedure	Quantity of photographs (pcs)	Quantity of tie points (pcs)	Quantity of control points (pcs)
Analytical	4163	65122	11963
Digital	3103	94585	13502
Altogether	**7266**	**159707**	**25465**
Quantity of unknowns	*43596*	*479121*	

Table 3. Summarized statistics of the aerial triangulation results [1]

From Table 4, one can state that the accuracy of the countrywide geometric fitting of the original aerial photographs can be described by ± 0.20–0.25 m X,Y co-ordinate mean error that is a very good value.

Aerotrian-gulation procedure	Field accuracy			Accuracy projected onto the image plane		
	m_x (m)	m_y (m)	m_z^* (m)	m_x (µm)	m_y (µm)	m_z^* (µm)
Analytic	± 0.23	± 0.26	± 0.44	± 7.5	± 8.5	± 14.6
Digital	± 0.16	± 0.16	± 0.10	± 5.5	± 5.3	± 3.0

Table 4. Summarised accuracy of the aerotriangulation performed in blocks [1]

* The result of m_z of digital aerialtriangulation is only a theoretical (mathematical) value and not a real one. The real value of determination of Z co-ordinate is the result of analytical triangulation, e.g. ± 0.44 m.

2.2. MADOP (National Orthophoto Program of Hungary)

Based on the results of "Aerial Photography of Hungary 2000" , the aerial triangulation and the later mentioned high resolution DEM the MADOP program has been executed by private companies (Eurosense Hungary Ltd., and CartoHansa Ltd.) and FÖMI.

Characteristics of the new digital orthophoto database:

- resampled orthophotos to 50cm ground resolution, cut by the 1:10 000 scaled topographic map sheets, (all: 4098 sheets of orthophotos)
- data format: uncompressed GEOTIFF,
- colour depth: 24 bit (true colour).

Corresponding the EU norms and using image-field identical points – in a random distribution all over the territory of Hungary for 259 map sheets – we made the X,Y co-ordinates of the orthophotos checked, in average 15-25 points/map sheet with GPS measurements (GeoLevel Ltd.). The results of this supervision summarised by the phases of performance (Table 5) verify that we managed to create a geometrically correct, highly accurate digital ortophoto database for the whole territory of Hungary , and which represents the status of the country in the year of the Millennium.

Phase	Sheets (pcs)	Check points (pcs)	Rejected points (pcs)	Accepted points (pcs)	m_x (m)	m_y (m)
I.	99	1740	31	1709	± 0.65	± 0.60
II.	100	1737	21	1716	± 0.65	± 0.70
III.	60	1131	7	1124	± 0.58	± 0.55

Table 5: Summary of the results of the quality checking by GPS measurements of ortophotos [1]

3. Raster database of the 1:10 000 scale topographic maps of Hungary and vectorisation of contour lines

During the execution of the twin projects the creation of the raster database of the 1:10 000 scale topographic maps of Hungary also has been started. This project was one of the most interesting project from the point of view of the creation of high resolution DEM, since it was the base of the vectorisation of contour lines of the 1:10 000 scale topographic maps.

Characteristics of the raster database:

- covers the whole country (4098 map sheets),
- contain:
  - raster dataset of the *colour prints* of map sheets (24 bit true color, 300 dpi resolution, geocoded TIFF files),
  - raster dataset of *the layer of planimetry* (1 bit colour depth, 400 dpi resolution, geocoded TIFF files),
  - raster dataset of the *layer of contour lines* (1 bit colour depth, 400 dpi resolution, geocoded TIFF files),
  - raster dataset of the *layer of hydrography* (1 bit colour depth, 400 dpi resolution, geocoded TIFF files).
- totally 4x4098 = 16392 map sheets in raster files.

Based on the raster dataset of contour lines the vectorisation of them has been started. Before the vectorisation project we asked two independent bodies to check the contour lines layers that they satisfies the requirements of the accuracy norms of the T.1. (Hungarian Topographic Regulation). The two independent bodies were the Department of Photogrammetry and GIS at the Technical and Economic University of Budapest and the Department of Photogrammetry at the College of Geoinformatics at the University of Western Hungary. Quality check was carried out by stereophotogrammetric measurements by the TEUB and by GPS measurements by UWH. The results are shown on Table 6.:

Assessment performed by	1[1] m		2.5[1] m		5[1] m	
	pcs[2]	z (m)[3]	pcs[2]	z(m)[3]	pcs[2]	z(m)[3]
Department of Photogrammetry and GIS, Technical University, Budapest	815	±0,56	1826	±1,03	35	±1,0
College of Geoinformatics Univ. of Western Hungary	2316	±0,47	2313	±0,73	-	-
Accuracy norms of creation of contour lines by Technical Instruction T.1.		*± 0.40*		*±1.0*		*±2.0*

Table 6.: Accuracy control of contour lines of the topographic maps at scale 1:10 000 [1]

Remarks:

[1] – value of contour interval on the map
[2] – quantity of points involved in the examinations
[3] – mean error of „Z" differences given in meters

These results calmed us, that we could start the vectorisation of contour lines for started the producing a high resolution DEM. The whole vectorisation process spent 3 years and mainly carried out by private firms, but approx. 900 sheets was vectorsed by FÖMI staffs, who executed the quality check procedure of the vectorised contour lines.

The digital vector contour lines are stored in 3D MicroStation DGN format. This digital databese of contour lines was the base of the preliminary high resolution DEM.

4. Quality check of digital contour lines

The vectorised contour lines has been put through a very strict quality measurements by FÖMI. The quality measurement procedure contains different traditional and own-developed method for checking which will be detailed in the following sections.

4.1. Visual checking

4.1.1. Check of inner quality assurance

FÖMI required from the private companies, who carried out the vectorisation procedure, a strict quality assurance method, which must be documented in paper and digital form. This check investigated that the company executed the quality check of the data or not. The check contains a formal and content check of the documents too. [2]

4.1.2. Check of completeness and levels

Each feature of the datafiles must be on a certain level and all the vector lines must be coincident with the raster lines of contour lines. This check was executed with the graphic environment (Bentley MicroStation). [2]

4.1.3. Connection of sheets

The check of the connected sheets was also carried out by visual way. There were many problems mainly because of the:

- Different contour interval of the neighbour sheets,
- The companies vectorised the contours in 2D and then lifted to a certain height. Because of this semi-automatic procedure we detected many problems in height.
- In many cases planimetry covers contours and therefore it is hard to interpret the correct height of a certain contour. Because of this misinterpretation we found many errors. [2]

4.2. Checking by software

4.2.1. Checking the height of contours

The requirements of FÖMI do not allow any height error in contour lines. To check this requirement we developed a software in MicroStation environment. The software checks:

- zero heights within the contours,
- the requirement of equal height within a contour.

The software has graphic and documented output too, for the necessary documentation of quality check. [2]

4.2.2. Checking duplicate points

Generally a contour does not contain only one graphic element in vector form. This check controls that in any horizontal position two or more different heights exist. This check was carried out and documented by GEOPAK GeoTerrain software. [2]

4.2.3. Checking crossing contours

Since the contours are isolines they must not cross each other. For the checking and documenting of this fact we also used GEOPAK GeoTerrain software. [2]

4.2.4. Checking by convolution index

Convolution index is a factor, which shows, that in a certain point of a grid model, the surface of the grid shows a regular or irregular characteristics. Convolution index in a certain grid point can be calculated from the height value of the neighbour points with the following formula:

$$C_{I,J} = | (h_{i,j+1} - h_{i,j}) - (h_{i+1,j+1} - h_{i+1,j}) |$$

As it seems, for the checking of convolution index first we had to generate a GRID model for the certain map sheet. The GRID model was generated by TIN->GRID method, with linear interpolation of heights from the TIN to GRID model. For the generation of TIN model only the contour lines were used.

We have to lay down, that the convolution index does not show error in the grid points, just highlights some irregularity. Therefore we have to fix a threshold value for the index to check a certain grid's points. Our experiences showed that the major contour interval of the sheet is the best threshold value to check the regularity the surface.

The convolution index check was executed by an own-developed software in MicroStation environment. For the production of GRIDs, GEOPAK GeoTerrain software have been used.

The results of convolution index checking showed, that this method is a very efficient automatic quality check procedure for GRID models and digital contour lines. [2]

4.2.5. Profiling

This software also developed by FÖMI in MicroStation environment for the quality check of GRID models. In our approximation profiling means the following procedure:

- we check all grid point along X and Y axes of the grid,
- condition:
    - the height difference between two neighbour grid points must not be more than the major contour interval of the original topographic sheet.

Similar in the case of the convolution index, the output of this automatic check does not show errors, just highlights some irregularity of the surface. The experiences showed that this quality check method is not as effective like the utilisation of convolution index. It could be because of the condition. Further investigation needs for the usage of this method. [2]

5. Generating of Preliminary DEM

After the execution of this strict quality check, the generation of the so called Preliminary DEM has been started. Preliminary DEM in our approximation means a GRID model, which is generated only from contours, with linear interpolation of an intermediate TIN model.

From the vector dataset of contour lines the Preliminary DEM has been created for the all 4098 1:10 000 scaled topographic sheets of Hungary. The format of the grids is a generic binary format, which contains height values in a matrix structure, started from the North-West corner of the grid. The resolution of the grid is 5m, so a full sheet contains 1201 columns and 801 rows. The height values are stored in Signed 32 bit integer format, with "cm" precision. Each grid has a header file, which contains:

- the EOV (Uniform National Projection System) horizontal coordinates of the North-West corner of the grid,
- resolution (5m),
- Number of columns and rows,
- Unit of heights (cm),
- Binary number format (Signed 32 bit integer).

This generic binary format provides that HUN_DEM files are flexible imported to any GIS or CAD system.

6. Correction of Preliminary DEMs

Preliminary DEMs can be used for orthorectification of digital images if there were no changes in relief and the characteristics of the relief were described by contours. But in general cases it is not true. On the cartographic materials (map sheets) there are special features of the relief, which are not described by contours (e.g. banks, cuttings, benches, chines). These features have not been taken into account in Preliminary DEMs and therefore these DEMs are not applicable to orthorectification.

Solving this problem we started another minor project, within the frame of MADOP program, for the correction of preliminary DEMs. In the project we appointed the following goals:

- detect the changes in relief which relative height difference is larger than 1m from the Preliminary DEMs by stereophotogrammetric measurements based on the photographs derived from "Aerial Photography of Hungary 2000" program (scale 1:30 000),
- insert special features (see above) into the Preliminary DEMs,
- generate a new "Corrected" DEM from the stereophotogrammetric measurements with the same characteristics like Preliminary is.

This project was executed together with the generation of orthophotos (since the Corrected DEMs are necessary for these procedure). The special features inserted into Preliminary DEMs were mainly breaklines. Generation of GRID model was solved by TIN-GRID method with linear interpolation. The reason of the use of linear interpolation was that our main clients are engineers, who need correct height information for design and therefore the more angular GRID of linear interpolation is better used in these cases.

The project successfully executed and a strict quality check procedure (see section 4.) accomplished. The results of checking by IV. order horizontal control network can be seen on Table 6.:

	Distribution of basic contour intervals			Total
Contour interval	1 m	2,5 m	5 m	
All points (pcs)	25118	25372	2653	53143
Rejected, difference >2.5 m (pcs)	617	672	229	1518
Accepted points (pcs)	24501	24700	2424	51625
RMS (m)	*0,58*	*0,71*	*0.99*	*0,67*

Table 6: Comparing the Z co-ordinates of points of fourth order network and the elevation of HUN_DEM [1]

Height differences, larger than 2,5m were rejected, because these heights referenced to point marks, which were not corresponded to the surface of the Earth. The quality check results show that HUN_DDM, the high resolution DEM of Hungary is a very reliable dataset, which can be used in any GIS project local, regional or countrywide level.

7. Conclusion

As joint achievements of the EU ANP Harmonization Programme of the Ministry of Agriculture and Rural Development and that of the MePAR (Agricultural Parcel Identification System), the following items were completed between 2000 and June 2003, and in the sequence of their completion they have continuously been serviced:

1. „Aerial survey of Hungary 2000" (at scale 1:30 000, from a height of 4500 meters, resulting altogether 7746 pieces colour slides, 6667 pieces of photographs digitized by scanning);
2. Aerotriangulation more than 6667 photographs;
3. Geocoded raster dataset of 4x4098 pieces of topographic map sheets/overlays at scale 1:10 000;
4. Vectorized relief of 4098 pcs map sheets and based on them a DEM of grid-density 5mx5m, comprising about 4 billion points;
5. 4098 digital orthophoto sheets of a volume about 2.5 TB.

As it was documented, all work phases were followed by strict quality control procedures. As a result of it, the digital orthophotos can be characterized by a co-ordinate error of ± 0.60 m and ± 0.70 m, which shows that HUN_DEM's reliability is very good.
The reliability of HUN_DEM is ± 0.70 m in average for the whole territory of Hungary. The digital elevation model can also be used independently for producing maps servicing the flood protection, logwater protection, maps of accurate slope categorization, showing the disposure, etc. The servicing of the HUN_DEM started in 2004. [1]

8. References

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