PUTTING THE PIECES TOGETHER : COMPOSING A NATIONWIDE DEM-COVER OF BELGIUM

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Commision IV, Working Group IV/6

KEY WORDS: Multisource, DEM, Combination, Modeling, Production, Inter-operability

ABSTRACT:

Ideally a country (region, city, etc.) is covered with homogeneous data sets. Unfortunately, this ideal situation does not often present itself. Frequently, we have a number of different existing data sets with varying characteristics at our disposal. One then has the choice between starting all over from scratch in order to get a new homogeneous coverage or trying to combine the existing data and filling in the gaps. The decision between the two options is a matter of a number of "pushing" and "pulling" factors as for example available production means, urgency, required precision, market situation, etc. At the Belgian National Geographical Institute a project was started in 2001, aiming at the maximum use of the existing data sets in order to quickly set up a DEM with medium-scale accuracies for the whole country. Overall, we used more than five different sources and methods for the collection of digital elevation data, resulting in a nationwide DEM-patchwork. In one of these workflows we combined different powerful commercial softwares for the automatic generation and filtering of a DSM. When different sources of data are available for the same area, it can be very useful to combine the different characteristics and exploit the diversity of the data in order to improve the quality. An example of this is the combination of automatically generated DSMs with DTMs derived from digitized contour lines. In a densely populated area like Belgium, with highly irregular man-made landscapes, it is not always feasible (in a cost-effective way) to filter the DSM down to a DTM. A second DTM based on digitized contour lines serves as an additional information source for solving this problem. The overall accuracy of the latter DTM is lower in places where the DSM describes the earth surface, but on the other hand it helps to detect where the DSM does not coincide with the ground surface. Tests were performed for the automated and semi-automated exploitation of this diversity.

1. INTRODUCTION

The Belgian National Geographical Institute (NGI) is the National Mapping Agency for Belgium. Besides its traditional production of paper topographical maps (1:10.000 1:20.000 1:50.000 1:100.000 1:250.000 as standard products) and raster image equivalents, the NGI produces several digital vector products such as 2D geographical databases and 3D CAD files as well as orthophotos. A merging of the 2D databases and 3D CAD files into one single 3D database is planned for the near future. The assembly of a multisource DEM fully covering the country as a multi-purpose reference layer was started in 2001.

This paper gives an overview of the DEM situation at the NGI, the present and future DEM requirements and the general methodologies that are being used to meet these requirements. The last part of the paper deals with a test which we performed to produce a DTM combining three different data sets with complementary properties and which are readily available at the NGI. We discuss some preliminary results and the possibilities of introducing a higher degree of automation in the tested production process.

The following terminology is used. A Digital Elevation Model (DEM) can be a Digital Terrain Model (DTM) or a Digital Surface Model (DSM) or a mixture of both. The surface in a DSM corresponds to the surface that is visible on aerial images or satellite images. A DTM models the ground surface.

2. COMPOSING A DEM

2.1. The DEM situation at the NGI up to the year 2001

A full DTM coverage of Belgium (30 000 km^2) is available in DTED (STANAG 3809) level 2 format. It has a height resolution of 1 m and a grid interval of 40m in the northern and central part of the country and 20m in the southern part. The poor height resolution gives rise to artefacts in several applications. For two thirds of Belgium there are DSMs derived by correlation of aerial images on a scale of 1:43 000 that were originally used for the production of orthophotos. For 17% of the country a number of DTMs were constructed by manual stereoplotting of points and structurelines on aerial b/w photographs on 1:20 500. These were only produced for areas where the terrain is not too flat and for areas which are not too forested. Untill 2001 a lot of information on terrain height was still in analogue form, consisting mainly of contour lines on a map scale of 1:10.000.

2.2. DEM requirements

Within the NGI there is a demand for a better DEM for the production of orthophotos. Since 2002 we have switched from using 1:43 000 imagery to 1:29 000 and occasionally going up to 1:20 500 imagery. The available DSM data, complemented by DTED level 2, were of sufficient quality for processing of the 1:43 000 imagery. However, for the larger scale imagery we need a better DEM.

There is also a demand for a DTM which is to be used as a reference plane in the future 3D geographical database. As the accuracy of most of the topographical data is situated in the 0.5m to 2m range, a DTM with at least similar accuracy is needed. This DTM should also be usable for the derivation of contour lines for topographical map production.

The NGI performs regular surveys for the identification of obstacles around airfields. The scope of these surveys has been widened in the last year to almost the complete Belgian territory. A reliable DTM is a prerequisite for this kind of studies.

There is an increasing demand for DEM products from customers. The requirements are highly variable. They range from small scale DSMs for draping satellite images over detailed DTMs for geomorphological studies to line of sight studies for the telecommunications sector. Priorities for most customers seem to be: full coverage, reliability, ease to use and a low price. On the one hand there is a general demand for an off-the-shelf product, but on the other hand requirements vary very considerably and frequently tailor-made solutions are needed.

2.3. Production constraints

Available budget and personnel are limited. There is considerable urgency, especially for the production of orthophotos.

The regions in Belgium (Flanders, Wallonia and Brussels) are also involved in production programs for DTMs. Although co-operation is agreed upon, practical as well as legal and financial issues still need to be settled. As a consequence we look actually for a moderate cost intermediate solution. This situation has an important influence on the data structure and working philosophy.

2.4. Recovery and flexibility

A huge amount of information has already been collected in the previous decades in the form of contour lines on a map scale of 1:10.000 that were stereoplotted and verified through extensive field surveys (Vanommeslaeghe,2001). The contour lines are still very useful as a source for DTM production. As the recovery of the information (from analogue to digital form through vectorization and identification) is a lot cheaper and faster than starting over from scratch, it was decided to pursue the recovery and upgrading of existing information as much as possible.

The quality that should be achieved is an overall accuracy of 0.5m to 2m. If this quality level is not achieved or not yet achievable, a quality should be achieved which is at least better than the existing DTED level2.

Budgetary constraints make it necessary to use different types of data sources and it is very likely that external data will need to be incorporated rendering data-interoperability a very important feature of the project. Likewise, a lot of different derivatives are foreseen and possibly more will become necessary. Because of time constraints, in certain areas it will be necessary to use an intermediate suboptimal solution which will have to be replaced with better data later on. In view of this situation the project should work in a very flexible way. We avoided making a very detailed conceptual model because it is dangerous as it taxes the ability to adapt to new situations and technical possibilities. You do however need an overall conceptual framework as a tool to guide the actual work.

2.5.Working priorities

Whether a DTM qualifies as a “good DTM” depends on a number of factors. First and foremost this question should be rephrased into “Is the DTM making the things possible that you want to do in your specific application ?” It is a question that has a different answer for every different user. In our experience we can corroborate the breakdown of the goodness of a DTM in the following factors as given by Cory and McGill (1999): completeness, reliability, consistency, uniformity, content, accuracy . In our experience most customers’ questions pertain to the first two factors (i.e. when these are not fulfilled there is no interest and so other factors are not relevant).

Although every factor is theoretically important, due to constraints it is not possible to focus on each factor at the same time. Hence we will follow a phased production process. In a first phase we tackle the completeness and reliability, relegating the other factors to future phases. We strive to get a complete coverage of Belgium with a quality at least better than the existing DTED level 2. In a second phase we will perform a systematical quality assessment, the objective of which is to guide the following “upgrading” phase and to provide users with useful metadata. In a third phase we need to upgrade the accuracy where it is not within the 0.5-2m range. If necessary a further upgrading to higher accuracies can be pursued.

After upgrading the whole data set, the next phase is that of updating the data. Compared to other topographical data, this is expected to be a smaller problem, if the accuracy range is kept at 0.5 to 2m. Higher accuracies would of course cause a bigger need for updating.

2.6. Data structure

A threefold structure is guiding the production. On a first level we have the so called DEDS (Digital Elevation Data Set). These are the original discrete data on terrain (or surface) height whatever their origin. On a second level we have actual DTMs (or DSMs) derived by interpolation of heights in between the original discrete data. As there are a variety of interpolation strategies and techniques and an equally wide variety in user requirements, many different DTMs (and DSMs) should be (at least conceptually) envisaged on this level. For the practical reason of having only one easily manageable and off-the-shelf product that is suitable for the majority of end users, one DTM will be made as a general reference GIS layer and only locally a second DEM will be made where the demands for different applications cannot be met by a single DEM. The most obvious application is the production of orthophotos where locally a DEM should be provided including the surface of large structures such as fixed bridges, etc… For easy distribution and handling, it will be made available in tiles of 4 km^2 like the

already existing orthophoto product at the NGI. In order to combine the advantages of a grid approach (volume, easy transferability to the users of rasterdata) and a TIN-approach (preserving the linear structures) a hybrid form is envisaged. It should however always be possible to derive differently structured DTMs directly from the DEDSs, for example in case we want to work directly on digitized contour lines as described by Mizukoshi and Aniya (2002). It is therefore of paramount importance that the DEDSs alone are considered as the core data.
On a third level we can envisage all kinds of derivative products such as contour lines, viewshed analysis results, …).

2.7. Available data sources

The following data sources that contain information on terrain height are available for the production of a better DEM:

- Points at ground surface and structure lines that were stereoplotted on aerial b/w photographs on 1:20.500 specifically for DTM production (DTM10.000 type1), available for 17% of the country but more will become available through co-operation with the regions.
- Points from airborne laser scanning (about 1 point/25m^2)These are at the moment only available for 160 km^2 but in due time much more may become available through co-operation with the regions. (The derived DTM is known as DTM10.000 type 2)
- Points at ground surface measured by terrain survey. These are available for a small number of very flat areas. The accuracy is very good (RMS 0.4m) but the data do not include points on linear terrain features. Addition of linear elements (e.g. dikes) could remedy this. (The derived DTM is known as DTM10.000 type 3)
- Contour lines that were stereoplotted using aerial b/w photographs on 1:20.500 and 1:10.000 for flat areas. Both were extensively checked in field surveys. These are available for a very large part of the country in vector format. Their general quality is quite good but locally gaps and blunders are present. (The derived DTM is known as DTM10.000 type4).
- Linear elements (embankments, hydrographical elements, …) in 3D that were stereoplotted for the production of a topographical map. The elements that are at the ground surface are a very interesting additional source of data for the build-up of a countrywide DTM (Ruiz,2000). Before integrating them, a selection and thorough control of the z-values is necessary as the emphasis in the past has been more on their planimetrical position.
- Points from image correlation on aerial b/w photographs on 1:20.500 and 1:29.000. These are only available for a small part of the country but can be quickly derived for almost the whole country, as it is completely covered with the necessary aerial photographs.

Depending on the type of area a different kind of data source provides the optimal (within practical constraints) solution. Factors that are decisive in the choice of data source are the availability of the data source, the type of terrain, the amount of processing that has to be performed on the data source, the urgency of demand for data in an area,… Sometimes a suboptimal solution needs to be chosen as a stopgap which will be replaced with a better solution afterwards.

2.8.Quality issues

2.8.1. Accuracy. There are two reasons for a thorough statistical quality analysis. On the one hand it is needed as a guide for the upgrading of the DEDS. As such it is really a tool and not so much an end in itself. On the other hand it is necessary to give the users of the data (or derived DTMs) metadata which they can actually use to estimate the usefulness of the data for their application. Statistical results on the accuracy of discrete elements contained in the DEDS should be clearly distinguished from statistics on the accuracies obtained at random locations in the DTM.

We are setting up a separate DEDS which will only be used as a source of control points. The height accuracy is in the cm-range. Here again a policy of recovering past efforts is pursued by filtering suitable points at the ground surface from the thousands of control points used for aerotriangulation purposes in the past 15 years.

Preliminary results show that all four DTM10.000 types yield significantly better results than the existing DTED level 2 model. E.g. table 1.

	Flat terrain (H:3-10m)		**Hilly terrain (H:60-230m)**	
	DTM10.000 type3	DTED lv2	DTM10.000 type1	DTED lv2
Mean	-0.17	-1.30	0.39	-0.32
Variance	0.09	0.67	0.63	4.28
Deviation	0.29	0.82	0.80	2.07
RMS	0.41	1.59	1.06	2.30

Table 1: statistics on the height differences between check points measured in the field and values derived from a DTM. (H = terrain height)

A visual inspection of the data by an operator is a step that is labor intensive but that cannot be neglected. The real bottleneck in a production environment is always this phase for which there is however no valid alternative. Even for very automated and homogeneous techniques such as laser scanning, the expenditure needed for a good data verification is still significant (Artuso et al., 2003). Visualizing the DTM as a shaded image is a very effective way to quickly spot possible problems (see also Dupéret,1999), although other visualization techniques are also useful. A mixture of different techniques, preferably by different operators is still the best quality assurance policy. The visualization also gives a subjective, quite intuitive impression of the quality. A comparison of figure 1 and figure 2, both showing the same area gives a good impression of the improved height resolution of the model and hints at the better modeling of the terrain.

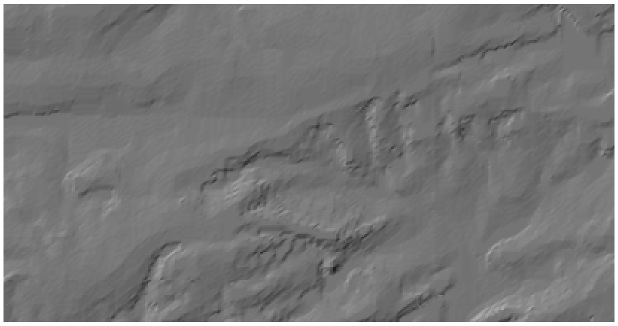

Figure 1. extract of DTED level2 as a shaded image

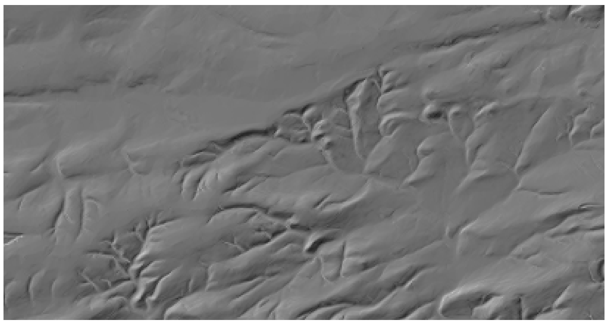

Figure 2. extract of DTM10.000type4 (based on digitized contour lines) as a shaded image

During the processing of the data, regular checks of consistency within the data itself or consistency with other data are needed to spot problems as early as possible. (e.g. contour line topological consistency, statistics on point clouds to eliminate outliers or spot systematic errors, …) Repeated checks and cross-checks are reliable ingredients for a good quality assurance policy.

2.8.2. Heterogeneity. Heterogeneity issues can be divided into two levels. Within one DEDS of the same type there may be quite some variation of quality. E.g. when data for a DTM are measured using photogrammetry, wooded areas will yield poorer results if any. The quality of manual measurements inherently varies from operator to operator, not only because of each individual appreciation of stereoscopic depth but also because of each individual interpretation of the elements making up the geomorphology. This kind of heterogeneity is inevitable but should be carefully considered when performing a quality analysis.
Between DEDSs of a different type there can be differences in geometrical accuracy and in data content. Stereoplotted contour lines will for example reflect a slightly generalized, interpreted "natural" landscape, excluding big artificial structures. Automatically measured DEDSs on the other hand will show no bias towards a "natural" or an "artificial" landscape. Reckoning with the differences in geometrical accuracy between DEDSs is relatively easy using classical edge-matching procedures. Taking into account the differences in data-content is however not possible. Consequently, an adjusting of the data content of the different DEDSs needs to be pursued as far as practically feasible.

3. THE COMBINATION OF DIFFERENT DATA SETS

3.1. Overview

When different DEDSs of the same area with complementary properties are available, it is possible to exploit this in order to spot problems and sometimes to remedy them. Studies have been made on the possibilities of combining a laser derived DSM with edgelines derived from image matching (McIntosh and Krupnik, 2002) and combining a laser derived DSM with spectral information from color aerial photographs (Haala, 1999). Laser derived DEDSs are in practice supplemented with photogrammetrically captured structure lines and field survey results (Reiss, 2002). Linear and polygonal elements are added to correct the height of points derived from image correlation (Dupéret,1999) and DTMs based on digitized contour lines are used for the early detection of gross errors in laser data (Artuso et al., 2003).

3.2.Test: goal and used material

We performed a test in two small areas in the Belgian Ardennes. The goal of the test was to investigate the possibilities to exploit the complementarity of different DEDS, not only in order to spot problems and guide the interactive work but also to introduce a degree of automation in the combination of the DEDSs. We chose to use DEDSs that were readily available for a large part of the country (digitized contour lines and 3D CAD files containing elements for the topographical map on 1:10 000) or that could be easily and quickly produced (DEM from image correlation). We also chose to use softwares which we already use. We have established a thorough experience with MATCH-AT (INPHO), ISSD (Z/I) + MicroStation (Bentley), automatic DEM derivation with VirtuoZo (Supresoft), TIN functionalities for DEM production with Terrain Analyst (Intergraph), DSM filtering and general DEM management and editing with SCOP and GVE (INPHO). For the test it was necessary to combine these softwares in one production chain.

Test area 1 includes a moderately wide valley flanked by relatively steep, wooded slopes. Area 2 has moderate relief in a more or less open landscape. In both areas the first DEDS consists of stereoplotted contour lines with a 5m interval based on aerial b/w photographs on a scale of 1:20.500. The overall quality of these contour lines is good but in the valley they are frequently missing. Along the river valley we find a number of quarries where contour lines are also missing. A second DEDS consists of a DSM generated automatically on a different set of aerial b/w photographs on a scale 1:20.500, with a posting of 20m. During the calculation of the DSM a partial filtering is performed by the software, eliminating to a large degree the small areas of higher elevation (trees, individual buildings) but not filtering larger areas of higher elevation (large structures, forest canopy).

3.3. Combining two data sets

The DSM is quite usable as a DTM in open areas but gives no indication of terrain height in wooded areas and it has the general disadvantages of an automatically generated DSM for which there are no remedies except interactive editing (Ackermann, 1996). On the other hand, the contour lines are generally very reliable even in wooded areas but are frequently missing or erroneous in the river valley and adjoining quarries, both of which are open areas.

Both DEDSs are recalculated to a regular grid with 20m posting. and the differences are analyzed.

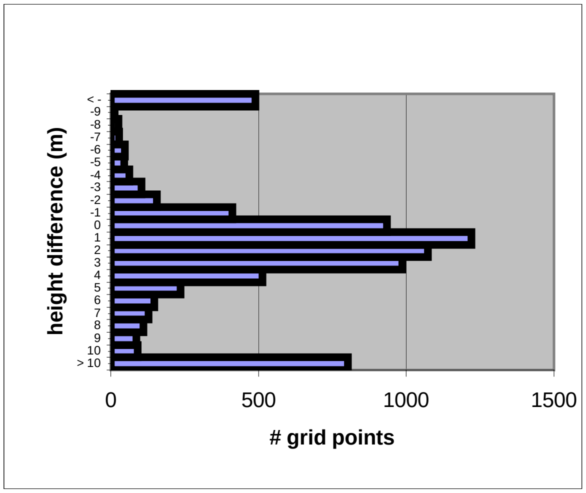

Figure 3. Test area 1. Z-value of DSM minus z-value of DTM based on contour lines.

For area 1, figure 3 shows a big deviation. The interesting values here are the differences with absolute values larger than 10m. In both cases they indicate situations where one of the two DEDSs is clearly not reflecting the terrain surface. Negative values indicate areas where the DTM based on contour lines is higher than the DSM. This is the case in quarries where contour lines where falsely interpolated and to a certain extent it reflects the lack of contour lines in the river valley which leads to a DTM somewhat floating above the valley bottom. Positive values indicate areas where the DSM yields values higher than the DTM, generally indicating wooded areas.

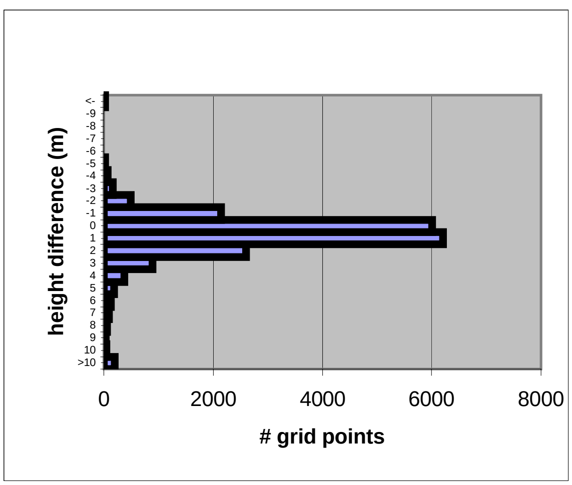

Figure 4. Test area 2. Z-value of DSM minus z-value of DTM based on contour lines.

For area 2 the average difference and variation are smaller than in area 1. There are no pronounced peaks above the absolute value of 10m. Both DEDSs here result in roughly the same DTM .

The differences can also be stored in a rastermap for analysis of the relation between differences and the topographical situation, as depicted in the following figure.

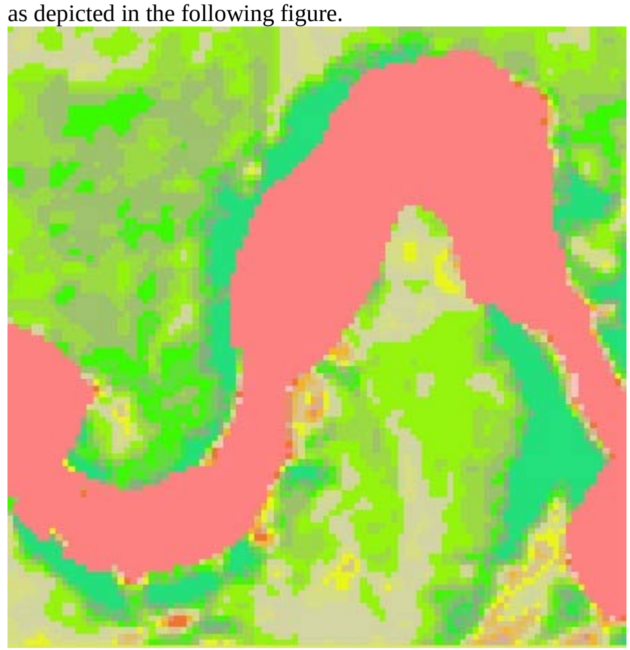

Figure 5. area 1: Differences in height between DTM based on digitized contours and DSM for area 1. Red to yellow = DTM higher than DSM. Green = DTM lower than DSM.

Figure 6. Orthophoto showing area 1.

The two datasets are combined into a third grid by taking for each gridpoint the lowest available value. This results in a genetically hybrid DTM which reflects the terrain better than either parent grid separately. In quarries and the river valley the DSM-derived grid points reflect much better the actual terrain height. In the wooded areas the DTM-derived grid points reflect the real terrain height. The rastermap with differences can always be used to establish the origin of each grid point in the hybrid DTM.

3.4. Adding structure lines

At places where slopes change abruptly (such as quarry edges, embankments and borders of water features) it is necessary to introduce additional linear elements. In the test these were taken from the data measured for the topographical map 1:10 000. Prior to their integration, their height was compared to the height suggested by the hybrid DTM. In figure 7 the results are given for the stereoplotted borders of water features for area 1. For the majority of the borders, their height is within 2m from the hybrid DTM. For the remaining borders, the hybrid DTM is several meters too high. This is mostly the case in places where no digitized contour lines were present and the DSM was too high due to vegetation. In these places it is necessary to incorporate the stereoplotted borders to correct the hybrid DTM.

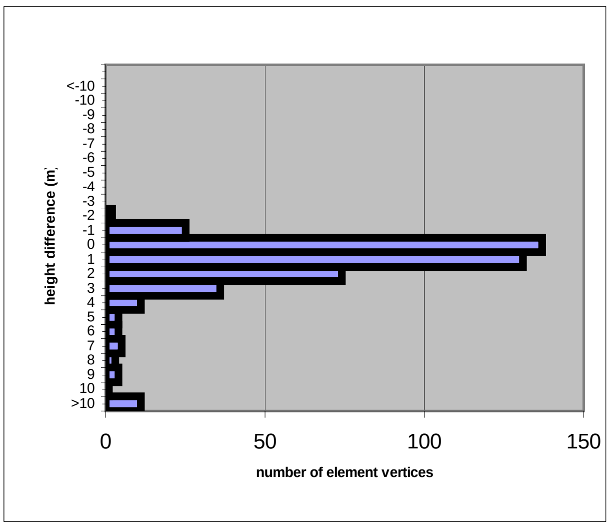

Figure 7. test area 1. Z-value derived from hybrid DTM minus z-value of stereoplotted borders of water features.

In the future, results from this kind of statistical analysis could be used to automate to a certain degree the incorporation of the stereoplotted elements as additional linear elements in the hybrid DTM. A fully automated procedure seems not very realistic and actually quite dangerous. At the moment it is still necessary to include the linear elements in a completely interactive way.

4. CONCLUSIONS

We have given an overview of the initial DEM situation at the NGI, the requirements for the development of a better DEM data layer and the constraints that have to be taken into account. We then proceeded with the general working strategy for the actual development of the DEM data layer, highlighting the need for recovery and upgrading of existing data, the need for flexibility, the need for a phased approach and an appropriate data structure.

A test was performed combining three available DEDSs using available software to construct a new DEDS which better reflects the terrain than any of the original DEDSs. Further testing should be performed to corroborate the positive results obtained and to heighten the degree of automation in the procedure.

REFERENCES

Ackermann, F.,1996. Report on the OEEPE Workshop on Application of Digital Photogrammetric Workstation "Some considerations about feature matching for the automatic generation of digital elevation models", Lausanne, Switzerland. http://phot.epfl.ch/workshop/wks96/art_3_4.html (accessed 23 jan. 2003)

Artuso, R., Bovet, S., Streilein, A., 2003. Report on ISPRS WG III/3 Workshop "Practical methods for the verification of countrywide terrain and surface models", Dresden, Germany. http://www.isprs.org/commission3/wg3/workshop_laserscanning/papers/Artuso_ALSDD2003.pdf (accessed 24 march 2004)

Cory, M.J.,McGill, A., 1999. Report on the OEEPE Workshop on Automation in Digital Photogrammetric Production "DTM derivation at Ordnance Survey Ireland" , Marne La Vallée, France. http://phot.epfl.ch/workshop/wks99/5_2.html (accessed 23 jan. 2003)

Dupéret, A., 1999. Report on the OEEPE Workshop on Automation in Digital Photogrammetric Production "DTM edition in IGN France. An operational process to generate contour lines", Marne La Vallée, France. http://phot.epfl.ch/workshop/wks99/4_2.html (accessed 23 jan. 2003)

Haala, N., 1999. Combining multiple data sources for urban data acquisition. In: *Photogrammetric Week '99*. Wichmann, Heidelberg, pp. 329-339.

McIntosh, K.,Krupnik, A., 2002. Integration of laser-derived DSMs and matched image edges for generating an accurate surface model. *ISPRS Journal of Photogrammetry and Remote Sensing*, Vol 56, pp.167-176.

Mizukoshi, H., Aniya, M., 2002. Use of contour-based DEM's for deriving and mapping topographic attributes. *Photogrammetric Engineering & Remote Sensing* Vol.68, No.1, January 2002, pp..83-93.

Reiss, P., 2002. Combination of Laser scanning, Digital Photogrammetry and Terrestrial Survey to generate high-quality DEMs. In: *Proceedings Joint International Symposium on Geospatial Theory, Processing and Applications*, July 8-12, 2002, Ottawa, Canada.

Ruiz, A., 2000. A countrywide TIN elevations database. In: *International Archives of Photogrammetry and Remote Sensing*, Vol XXXIII, Part B3, Amsterdam 2000, pp. 785-791.

Vanommeslaeghe, J., 2001. Het opstellen van een digitaal hoogtemodel voor België. Internal report NGI Belgium