

THE SCHEME FOR THE DATABASE BUILDING AND UPDATING OF 1:10,000 DIGITAL ELEVATION MODELS

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ABSTRACT

The National Bureau of Surveying & Mapping of China has planned to speed up its development of spatial data infrastructure (SDI) in the coming few years. This SDI consists of four types of digital products, i.e. digital orthophoto, digital elevation models, digital line graphs and digital raster graphs. For the DEM, a scheme for the database building and updating of 1:10000 digital elevation models has been proposed and some experimental tests have also been accomplished. This paper describes the theoretical (and/or technical) background and reports some of the experimental results to support the scheme. Various aspects of the scheme are discussed such as accuracy, data sources, data sampling, spatial resolution, terrain modeling, data organization etc.

1 INTRODUCTION

The National Bureau of Surveying and Mapping of China, as the governmental department in charge of the acquisition and management of geodetic and cartographic data on the whole national territory, aimed at the beyond century development of GIS and proposed so-called "4D products strategy". According to this strategy, the conventional production technology will be shifted to digital technology in the coming few years. Like the SDI of USA (USGS, 1992), 4D products here means DLGs (Digital Line Graphs), DEMs (Digital Elevation Models), DOQs (Digital Orthophoto Quadrangles) and DRGs (Digital Raster Graphs). Corresponding to the traditional topographic map series with various scales, 4D products are also arranged to be in different scale series, such as 1:10000, 1:50000, etc.. To produce these standard digital products and to ensure it will be shared and transferred among a broader users and producers, the corresponding specifications and standards must be firstly established.

Since the 1:10000 scale DEMs are more higher in accuracy and more larger in data amount than any other, the scheme for this kind of products then has to be more elaborate, and is also a good prototype for others. Therefore, this paper just chooses the scheme for the production of 1:10000 scale DEMs as the theme. DEMs as the SDI of a country are widely applied in various geo-related disciplines. Even though the application of DEM has been continued for about 20 years in China, but in the past the DEMs were built with respect to a limited set of predefined applications for different disciplines such as the production of contour maps, volume calculation, geometric rectification of remote sensed imagery, and so on. The format, the method of data acquisition and the accuracy requirement all are chosen with respect to these predefined applications, i.e. the DEMs as not standard products then can not be shared and transferred between different users. Since the digital products are quite

different from those of line maps in production, storage and propagation., many existed standards or specifications therefore are no longer valid.

This paper attempts to review some key issues about the provisional specification for DEM production (SISM, 1997), such as data sources, data sampling, spatial resolution, terrain modeling and data organization, and so on. It is hopeful to be a theoretical and technical background for the further perfection and practical application of this specification.

2 DEM ACCURACY

For a DEM project, there are three basic criteria, i.e. accuracy, cost and efficiency, must be considered to select different sources and schemes. As the most important quality control indicator, the accuracy of DEM is of concern to both users and producers. Following Li (1990), as expressed in Equation (1), the accuracy σ of a DEM is mainly dependent upon the accuracy σ_{raw} of its data source, spatial resolution (i.e. grid interval d), terrain characteristics (terrain slope α), and terrain modeling method (related to coefficient a and b).

$$\sigma = a \times \sigma_{raw} + b \times (d \times \tan\alpha)^2 \quad (1)$$

One factor influencing accuracy of raw data is source scale and resolution. For example, if the existing map is used as the source, only the map series with equal to or larger than 1:10000 scale can be adopted (this paper just considers the both scales of DEM and source as the same). The resolution of map is usually expressed as contour interval, thus the relationship between accuracy and different sources and resolutions needs to be examined. Fortunately, there have been many experimental research results available such as Li (1990, 1992, 1994), Balce (1987). Here, the authors just refer to some key conclusions of those directly:

- (1) If both the contour lines and specific points and feature lines (such as peaks, pits, ridges, break lines, etc.) are sampled, the accuracy of derived DEMs in terms of RMSE is about 1/6 to 1/14 of the contour interval depending on the characteristics of the terrain topography. However, if additional specific feature lines are not included, the accuracy can be reduced by 40% to 60%. Concerning with the feature specific data, both the magnitude and the occurrence frequencies of large residuals can also be reduced. If the terrain is discontinuous and complicated, this reduction could be significant.
- (2) The accuracy of a DEM derived from gridded data plus specific feature data is linearly related to the grid interval. However, if there is no feature data, the relationship becomes parabolic, and the accuracy of DEM will be decreased more quickly as the grid interval is increased.

In the following sections, the scheme about the data source selection, sampling strategy and modeling, depends on which the required accuracy and reasonable cost and efficiency can be achieved, will be discussed.

3 DATA SOURCES

The source data, comprising positional coordinates and elevation values, can be measured directly on the terrain surface by field survey methods or it can be obtained remotely sensed imagery, and/or existing contour maps. The method used will depend partly on the availability of these different materials but also on the scale or the required sampling interval and the accuracy requirements of the DEM (Li, 1990).

Since the production of 1:10000 scale DEM involves a large area extent and great deal of data, any kind of ground surveying methods, even through using GPS or total station can produce more accurate data of limited areas, are not practical due to their low efficiency. Similarly the height accuracy of remote sensing is also too low to become the appropriate data source for DEM generation.

Up to now, a large amount of basic topographic maps covering most of the country have been produced and updated continuously. These existing maps of course can be considered as the reliable and primary source of DEM. Theoretically speaking, 1:10000 DEM can be collected from any map series 1:500 scale through 1:10000 scale. Using the existing maps as the source, there are two problems have to be concerned, i.e. its currentness and the digitization of topographic symbols. For the economic developed regions, because of the land using the topographic relief has been changed with high frequency, the existing maps therefore are still not the good source. But for other regions such as the mountainous area, since the little change of terrain surface, the existing maps without doubt are the abundant and cheap data sources for DEM generation.

Aerial photogrammetry has always been the most important and efficient method for basic topographic map production and updating in China, it is also the vital and valuable data source for generating and updating the

accurate DEM with large area extent. For 1:10000 scale DEM, the basic specifications for aerial photography must meet the needs of that required for traditional 1:10000 scale map production.

4 DATA SAMPLING

As mentioned above, there are two main different sources for DEM data acquisition and updating, i.e. the existing topographic maps and aerial photographs. This section then just attempts to investigate the data sampling schemes from these two data sources.

4.1 Cartographic digitisation

The basic problem of data sampling from topographic maps at any scale is referred to the cartographic digitization for example the digitizing of contour lines using either manual or automatic line following digitizers or automatic raster scan digitizers. To satisfy the accuracy requirement as mentioned in section 2, sampling DEM data from existing maps, not only the contour lines but also the important characteristic points/lines should be included. At present, the semi-automatic raster scan digitizing methods are widely used for GIS applications in China rather than the manual tracing methods, so it is easy to digitize or to tag any kind of symbols.

4.2 Photogrammetric sampling

Photogrammetric sampling can be undertaken in any of several different ways, such as profiling, regular grid sampling, selective sampling and progressive sampling, which can be carried out through analytical plotter or DPW (Digital Photogrammetric Workstation). The basic problem is how to properly determine the density and distribution of sampling data points according to the accuracy and efficiency requirements. There are two main data distributions in practice of China that is the contour line and the regular grid. Based upon the comparison of the accuracy of contour based DEMs with grid based DEMs, it's suggested that contouring could be a better sampling strategy than regular grid sampling in areas with relatively steep slopes and smooth terrain (Li, 1994).

If analytical plotter is used, since the efficiency of dense regular gridded data sampling is too low to large-scale production, it's better to obtain digital contour data and terrain feature data by means of conventional working methods, and the sampling results also can be directly used for topographic map production purpose. However, if the DPW is used, the large amount of regular gridded data can be obtained by automatic correlation technology. Of course, additional important specific terrain feature data also should be obtained by analytical method. We have also tested the method of raw-grid plus feature-specific data sampling by "non-optic mechanical" analytical plotters made in China. Since the raw grid data are with a coarser interval such as 25m for 10m's DEM, the efficiency was still acceptable. Such method is recommended for those cases of flat terrain. The

experimental investigations into the variation of DTM accuracy with sampling interval based on data acquired using stereo-photogrammetric methods has been reported in (Li, 1992).

5 SPATIAL RESOLUTION

The spatial resolution of DEM represents the smallest spatial distance among grid nodes of DEM, is usually referred to as the grid interval. The dimension of grid interval directly determines the spatial integrity of DEM, or the terrain description accuracy. Moreover, the accuracy of DEM is also related to the grid interval, and in the areas with steep slope, the accuracy of DEM will be decreased rapidly along with the increasing of the spatial resolution (Li, 1992). The higher of the resolution, the more realistic of terrain expression and more data redundancy, vice versa. Concerning with different accuracy requirements, various topographic types (such as flat, hill and mountain), limited computer storage and reasonable small data redundancy, the basic spatial resolution of DEM must be determined properly.

The contour interval value was always used to weight the real terrain description accuracy of conventional map. The smaller the interval, the more detailed terrain expression, and vice versa. In principle, the accuracy of 1:10000 scale DEM standard products should coincide with that of 1:10000 scale topographic maps. To design the spatial resolution of DEM, the relationship between it and the contour interval has to be examined. As the results of comparison, there is the following relationship (Li, 1994):

$$d = K \times CI \times \cot\alpha \quad (2)$$

where α is the mean slope angle of the terrain surface, K is a constant and ranges from 1.5 to 2.0 in the case with the inclusion of feature data and from 1.0 to 1.5 in the case without feature data, CI is the contour interval and d is the grid interval.

If the feature data is excluded in the application of DEM, based on the surveying specifications of national 1:10000 topographic map and the terrain classification, the 1:10,000 scale DEM resolutions related to different terrain characteristics can be computed according to Equation (2), as shown in Table 1.

Table 1 Contour interval (CI) and equivalent DEM resolution (d) for various terrain slope (α)

| | | | |
|----------|---------|--------|---------|
| α | 2 | 15 | 45 |
| CI | 1 | 2 | 10 |
| D | 28 - 42 | 7 - 11 | 10 - 15 |

This is similar to that calculated from Li (1997). Generally, 10-meter grid interval can be used as the basic value for most natural terrain area, and if the database for specific feature also included, the basic grid interval then can be 20 meters.

6 TERRAIN MODELING

As the mathematical model of the terrain surface, DEMs are the terrain expression according to some specific methods based on the set of measured data points. At present there are two main methods for terrain modeling, i.e. TIN (Triangulated Irregular Network) based and regular grid based (Li, 1990, Zhu and Chen, 1998). Since the TIN-based methods can be used flexibly for any kind of data distribution, and can easily incorporate break lines, form lines, discontinuities and any other data. It's then always preferred for accurate modeling purposes. On the other hand, the grid-based methods because of simple data structure and convenient data handling are usually used for large-scale terrain modeling such as in a national range. The 1:10000 scale DEM database will be built to cover the whole country and will face various applications of different disciplines. Therefore it is suggested the grid-based terrain modeling should be used for standard 1:10000 scale DEM production. That means a DEM is an array of square grid points, and each node possesses only one elevation value. As this, only four neighboring vertices can be simply used to form a local bilinear surface to describe the corresponding lattice.

Since the DEM data is obtained in different patterns by different sampling strategies as mentioned before, additional special process is needed to form the grid-based network. The procedure from random distributed sampling data to regular grid network is referred to as random-to-grid conversion. Such conversion in fact is the data interpolation, and currently there are also many different methods for such purpose. Which method will be chosen just depends on the efficiency and the accuracy. The most common data interpolation method as patchwise methods usually involves the division of an area into a series of patches, and then constructing a local surface for each patch from all the data points located within the patch by employing a relatively low-order polynomial function and finally assigning height values to each grid nodes lying within the patch. As most of the patchwise methods face the difficulties of searching the neighbouring data points and of determining the weights when specific feature data concerned, thus the interpolation of regular grid nodes from triangular network is proposed, where the individual patch is just a triangle. For this purpose, the software developed in Wuhan Technical University of Surveying and Mapping, which has been used in practice such as railway and highway designs (Zhu and Chen, 1998), is available. Using this software the sampled contour data or raw gridded data combined with the feature lines such as ridges and break lines are then processed into the required gridded DEM with specific interval spacing.

7 DATA ORGANIZATION

1:10000 scale DEMs are organized according to the GB/T 13989-92 "Numbering System for National Large Scale Basic Topographic Map". The position coordinates of grid nodes can be UTM planimetric coordinates or geographic coordinates in 1980 national geodetic coordinate system, and the elevations of grid nodes are the mean sea level above values in 1954 Yellow Sea

elevation system. The DEM file is organized into three logical records in ASCII format or binary format respectively.:

Type 1, the metadata in ASCII format, consists information defining the general characteristics of DEM, including units of measurement, coordinate type, effective digit number of elevation data, data interpolation method, etc.

Type 2, the basic description of DEM in ASCII format, including the DEM name, original coordinates, grid interval, the number of profiles and the number of points along a profile, accuracy statistics.

Type 3, the main body of DEM in binary format, the profiles are organized from north to south and the points along a profile are organized from west to east.

As the application of DEM is usually in arbitrary dimension rather than an uniform range, such as to browse any part of a studied area. If the DEM files are strictly organized according to the specified boundary, there would be the mosaic problem during across different DEMs since the boundary of DEM is irregular. Ensuring the mosaic of DEM products to cover the whole studied area, the sampling dimension of each map should be larger than the largest outline rectangle of the standard map range. Otherwise, the final neighbouring DEMs should be coincidence in the boundary area through joining process.

Especially, for preserving the realistic terrain characteristics, it's better to store the specific feature data simultaneously as well as DEM for special applications.

8 EXPERIMENTAL RESULTS

In order to estimate the feasibility of the scheme described above and to estimate the accuracy of DEM products, the production experiment has been done recently in Guangzhou of Southern China. In recent experiment, only the aerial photogrammetry scheme was concerned since the methods of sampling DEM data from the existing map had been examined by many scholars before. Of course the further comparative study of the accuracy of standard DEM products from digitized contour data with/without specific feature will be carried out in the next experiment. Because there are two main different methods for photogrammetric production of DEM, i.e. by the analytical plotter and by the DPW, and also there are two quite different data distributions that is the contour lines and the raw grid nodes. This experiment just attempted to examine the efficiency and accuracy of these production strategies.

A brief description of the DEM source data is given in Table 2 (in which the SF stands for Specific Feature data).

The data sets had been acquired from two maps' area (named map1 and map2) on the analytical plotters using contour and grid sampling respectively, and on the DPW using digital correlation method automatically obtain grid data. The check point used in this test were measured

from more accurate field surveying in three kinds of terrain areas (flat, hill and mountain). The results in terms of the RMSE (root mean square error) are shown from Table 3 to Table 7, in which there are 5 different data acquisition methods as below:

- (1) Full digital automatic grid sampling;
- (2) Full digital interactive grid plus SF sampling;
- (3) BC2 based grid sampling;
- (4) BC2 based DLG sampling;
- (5) Existing map digitization.

Because of the limited amount of the field observations as check point, in order to assess all the data acquisition methods more comprehensively, the DEMs were also compared with that obtained directly from BC2 plotter. The results are shown in Table 7.

It is obvious that the DEM accuracy from grid sampling methods by BC2 plotter is better than that from any other in all kinds of terrain areas. But in our experience because of its very low efficiency, it is not a good choice for 1:10000 DEM production in a large extent. For the traditional contouring sampling method, if SF data is included in interpolation the accuracy would be increased evidently comparing with that without SF data. Especially, the accuracy of micro-computer based digital interactive grid plus SF sampling method is also satisfactory, and because the convenient automatic correlation technique is employed for measurement, it becomes an effective method. However, if only using the full automatic DPW for grid data acquisition, it is necessary to do much editing work for dealing with the gross errors and for considering the terrain features.

9 CONCLUSIONS

The following conclusions are available from this paper:

- (1) Both existing national basic maps at the scale of 1:10000 and aerial photographs are the two most important data sources for 1:10000 scale DEMs generation. Especially, the latter source is more vital for the purposes of updating and preserving currentness. To build 1:10000 scale DEM data base in a large area like a province in China, it is necessary to consider the regional difference during designing the data source, production scheme and the spatial resolution etc.. In order to utilize the limited manpower and material resources with reason. It's usually favorable to adopt multiple data sources, multi-resolution and manifold production modes.
- (2) Feature-specific data (FS data, such as the break-line and form line) is very important for ensuring the accuracy and efficiency of DEMs production.
- (3) Contours plus FS data collection based on analytical photogrammetry is better than gridded data sampling strategy in mountainous area. However if the terrain is comparable flat (i.e. the average surface slope is less than 15 degree), the grid data plus FS data sampling is a recommended method with high efficiency and enough accuracy.
- (4) According to the TIN based terrain modeling method to generate DEM products through any kind of random located raw sampled data is recommended for any type of topographic characteristics.

- (5) The grid interval with 10 meters is adopted for 1:10000 scale DEMs without complemented FS data in most cases, and the DEMs can be then used for most purposes equivalent to that used with 1:10000 scale maps. If the FS database is also built as complement, the grid interval of 20 meters can be used.
- (6) The data organization of provincial DEMs database is suggested in multiscale, in multiresolution and in hybrid format of ASC II and binary with complemented FS database

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Table 2 Description of test data

| Data source | Scale | Content | Instrument | Interval | Elevation Range | |
|-------------------|---------|------------|--------------------|----------|-----------------|--------|
| Aerial Photograph | 1:25000 | Contour+SF | Analytical plotter | 1-5m | map1 | map2 |
| .. | | Grid+SF | DPW | 25m | 0-120m | 0-369m |
| .. | | Grid | .. | 10m | .. | .. |
| Existing Map | 1:10000 | Contour | Scan Digitizer | 1-5m | .. | .. |

Table 3 The result from the flat area of map1(m)

| acquisition method | maximum residue | RMS |
|--------------------|-----------------|------|
| (1) | 7.4 | 3.23 |
| (2) | 3.2 | 1.34 |
| (3) | 2.43 | 0.96 |
| (4) | 3.34 | 0.76 |
| (5) | 3.34 | 0.80 |

Table 4 The result from the hill area of map1(m)

| Acquisition method | maximum residue | RMS |
|--------------------|-----------------|------|
| (1) | 18.78 | 2.60 |
| (2) | 9.14 | 1.24 |
| (3) | 4.17 | 1.05 |
| (4) | 3.17 | 1.16 |
| (5) | 2.55 | 1.12 |

Table 5 The result from the flat area of map2(m)

| Acquisition method | maximum residue | RMS |
|--------------------|-----------------|------|
| (1) | 5.14 | 1.86 |
| (2) | 4,26 | 1.16 |
| (3) | 3.12 | 0.77 |
| (4) | 4.18 | 1.52 |
| (5) | 4.17 | 1.53 |

Table 6 The result from the mountain area of map2(m)

| Acquisition method | maximum residue | RMS |
|--------------------|-----------------|------|
| (1) | 2.34 | 1.27 |
| (2) | 2.84 | 1.46 |
| (3) | 1.56 | 0.86 |
| (4) | 5.36 | 2.55 |
| (5) | 6.67 | 2.94 |

Table 7 The result of comparing with the DEM sampled by BC2(m)

| method | Map1 | map1flat | map1 hill | map2 | map2 flat | map2 mountain |
|--------|------|----------|-----------|------|-----------|---------------|
| (1) | 2.99 | 3.49 | 2.66 | 7.03 | 2.47 | 5.94 |
| (2) | 1.61 | 1.21 | 1.52 | 3.80 | 1.17 | 2.79 |
| (4) | 2.33 | 1.33 | 1.26 | 3.36 | 1.50 | 2.58 |
| (5) | 1.50 | 1.31 | 1.26 | 3.36 | 1.49 | 2.52 |