INTERACTIVE DTM DATA ACQUISITION AND VERIFICATION ON COMPUTER SUPPORTED ANALOGUE STEREOPLOTTERS

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ABSTRACT:

Analogue stereoplotters are still in use in many surveying agencies all over the world. Requirements for digital data and performances of PC computers make it necessary and possible to upgrade these instruments into efficient systems for digital mapping. Low cost software solution which does not include full upgrade into analytical instrument is presented. The main emphasis in this paper is on the software support to interactive acquisition and verification of DTM data. Basic concepts, applied algorithms and the first results are described. Solution is realised as a module of the MapSoft software system. The MapSoft is official software in Yugoslavia for support to acquisition, processing, analysis, maintenance and distribution of large scaled map data. Brief description of MapSoft and basic concepts of technology of digital mapping called Digital Geodetic Map (DGM) are also presented.

1. INTRODUCTION

Survey agencies in Yugoslavia, except military ones, have only analogue photogrammetric instruments. Currently, there are very small chances that this situation will be much better in future. Therefore, these instruments are still going to play a considerable role in geodetic practice for a long period of time. On the other side, fast development of computer technology has provided personal computers with enough power to support the most demanding tasks in digital mapping.

The result was a development of various photogrammetric software at the Chair for Photogrammetry and Cartography (Institute for Geodesy, Faculty of Civil Engineering Belgrade). This software is designed to serve as a support to analogue stereoplotter equipped with encoders and connected to a PC compatible computer under MS DOS.

The last software product in this series is MapSoft (Mihajlović, 1996). At the beginning, the MapSoft was primarily a software for support to interactive photogrammetric digital mapping. After achievement of this goal, modules for support to other data acquisition techniques and for some other applications were developed within the MapSoft. Therefore, support to photogrammetric data acquisition has become only one among numerous MapSoft's functions.

Simultaneously with the development of MapSoft, a constitution of the conception of Digital Geodetic Map (DGM) in Serbia was going on. This conception, which has been proclaimed in official survey regulations, covers a complete technology for production, maintenance and distribution of large scaled map contents in completely digital form. The basic concepts of the DGM and MapSoft will be included in the paper in more details.

To provide complete support to DGM, some changes of MapSoft were necessary. At the beginning of development of the MapSoft, attention was paid to the DGM data such as: parcel boundaries, buildings, communications, pipes, etc. Even though every entity in data base contained the third coordinate, it was in essence only horizontal representation of objects in the field. For the full implementation of the DGM concept, it was necessary to extend MapSoft's data base with other height information. The application of technology of Digital Terrain Models (DTM) was the only solution that could be satisfactory.

The applied solution is described in this paper. It is realised as the MapSoft's software module and it provides support to various techniques of DTM data acquisition. One of the most important is DTM measurement on analogue stereoplotters connected with PC computer. The functions for data verification are based on generation of TIN based DTM which serves for subsequent data analysis. The results of this analysis help operator to detect and eliminate erroneous data and to improve the quality of the acquired DTM by additional measurements.

2. DGM AND MAPSOFT

Considerable efforts have been made in survey agencies in Federal Republic of Yugoslavia towards utilization of computer technology within standard survey activities. Unfortunately, a lot of projects have failed. The main reason for this was that they were either based on poor foundations offering only partial solutions or they were too ambitious to be completed.

Certainly one of the most important efforts giving good results has been involvement of the concept of Digital Geodetic Map (DGM) in survey practice. DGM is a parcel based Land Information System composed of three vital components: data, software and hardware. It provides all the functions that were available using conventional large scaled maps, greatly improved in terms of automation level and accuracy, and extended with many new functions. The concept of DGM in the Republic of Serbia is confirmed in a set of regulations proclaimed by state survey administration.

The core of the DGM is composed of topologically organised vector data. DGM concept requires the data for the whole project to be kept in a single data base without any limitations caused by map sheet borders or any other divisions. Data base entities are not graphic elements (point, line, circle, arc, etc.) but objects in the field (spot, boundary edge, area) with the corresponding attributes. The regulations do not specify which data base management system should be used. Detailed specification of requirements that data (content and accuracy) and procedures for their acquisition, verification, archiving, maintenance and distribution have to satisfy are given instead.

Acquisition, processing, analysis and maintenance (update) of the DGM data are completely supported by numerous modules of MapSoft.

The MapSoft is a system with carefully designed and integrated modules. The main module of the MapSoft provides the following functions for the user :

- photogrammetric mapping, manual digitization using tablet digitizer and manual on-screen digitization of scanned maps as three major data acquisition methods;
- sophisticated detection and elimination of digitizing errors caused by distortions of the existing geodetic maps;
- input of the existing survey data in various forms;
- selection of data base entities for display and analysis using spatial or layer criteria;
- full set of functions for data base handling (browse, editing, search, statistics, etc.) in text or graphics mode (Figure 1);
- transparent on-line topology generation and update;
- recovering of damaged data base;
- data exchange with other systems (DXF, ArcInfo);
- support to various plotting devices;
- editing of symbol libraries;
- simple COGO and measuring functions.

Application modules provide the following functions:

- area calculations with polygon overlay functions;
- DGM data base maintenance with history of changes;
- advanced COGO functions;
- DTM module.

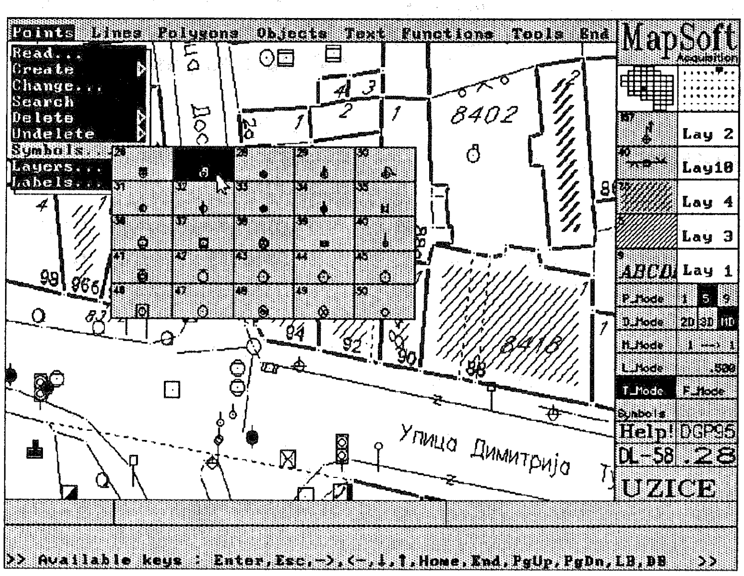

Figure 1 : Interface of the MapSoft

Acceptance of the DGM by survey agencies was initiated by appearance of the MapSoft software system. As it has been already mentioned, this software is a PC based solution for the realisation of the DGM concept.

It has been widely accepted fact that data represent one of the most important components of any GIS/LIS. One of the most important roles of MapSoft is to provide survey data necessary for realisation of various GIS projects in future. Therefore, MapSof/DGM data are structured in a manner which ensures their full utilization by GIS. The main concern of MapSoft is to secure the quality of the acquired data in terms of completeness and accuracy, which can be realised through adequate functions for data acquisition, primary analysis and processing. The optimum solution for achieving this goal, which has been applied within MapSoft, is interactive verification of data during the acquisition stage. Of course, it is understood that procedures for making these data official, and their constant updating are equally important. The same principles were used in realization of the module for the DTM support.

3. THE SOFTWARE CONCEPTION

There are several requirements that were imposed to the software:

- For efficient and high quality digital terrain modelling, it is essential to enable measurement and processing of all kind of the DTM data. This includes selective, systematic and progressive sampled data as well as the data from contour digitization. Height information such as structure and break lines and flat areas have to be fully respected.
- Interactive and efficient data measurement, verification and editing are required. Functions for visual and rigorous analytical checks of the acquired data must be provided. This should be based on analysis of the DTM created from the acquired data.
- The software must follow the basic conception of the MapSoft in order to be fully integrated with other modules. Already developed user interface should be used as much us possible to make the training easier.

4. THE SOFTWARE REALISATION

Standard functions of the MapSoft: data base management, functions of the graphical interface, measuring device support, plotting and the like were used for the development whenever possible.

The software is implemented through the design of data base and through the development of functions for data acquisition, DTM creation and DTM analysis and data verification.

4.1 Data base

The existing MapSoft data base has been extended with new spatial entities. The flexible data model includes spot heights, characteristic terrain lines, measured contours and areas (lakes, the areas under the objects, and so on).

Two optional solutions for extension of MapSoft with the DTM module have been considered. Each of them assumes that the existing MapSoft's data base has to be extended with spatially and topologically organised DTM data.

The first solution, which is currently implemented, assumes that only basic topology necessary for handling DTM data is stored and updated within MapSoft's data base. TIN based DTM is generated only for selected part of the project area at the moment when the analysis of that area is required. This simplifies and speeds up functions for data input and update. This is useful during data acquisition stage when a large amount of data is to be processed within on-line measurements. However, after data editing or after the new measurements have been done, the DTM has to be generated again. This has to be done every time the verification of the acquired data is to be made. When the data acquisition and verification are completed, the final DTM can be generated for the whole project area.

The second solution assumes on line generation and constant upding of full DTM topology for the whole project during data acquisition stage. After several measurements, updating of TIN topology and surface calculation are performed. The updated DTM data base can be used for further analysis right after. All in all, this solution is more efficient then the first one but it requires additional functions for updating of the DTM topology after each data editing. Otherwise, it should not be a problem to implement this algorithm. Due to the design of DTM data base these functions for DTM editing will be easily developed. It is important that the same functions for TIN surface generation are used in both solutions so the final results are the same.

4.2. Data acquisition

Using the existing MapSoft interfaces to digitization devices, the following data acquisition methods are supported:

- photogrammetric measurement
- on-screen manual digitization of the scanned maps
- digitization of maps on digitizing tablet.

The same principles apply to all three methods of data acquisition. The only difference is that in case of the second and third methods, heights for points and contours have to be entered manually from the keyboard. In this paper photogrammetric techniques will be considered.

All known strategies for the DTM data acquisition are supported. Of course, some modifications were necessary due to the limitations imposed by use of analogue instruments. This means that in case of systematic or progressive sampling, operator has to manually drive measuring mark to the marked positions that are chosen by computer for measurement.

Selective sampling is supported with functions for measurement of randomly located spot heights and characteristic terrain lines.

Systematic sampling can be done using profile or grid measurements. Once profile/grid parameters are set, upon each redraw of actual data window, theoretical locations for profile/grid points are marked on the screen. Of course, systematic sampling can be performed also by proper movements of stereoplotter handwheels to accomplish nearly regular distance between points during grid measurement.

Progressive sampling is based on analysis of TIN DTM generated from the points measured. This concept has already been presented in several papers (Bill, 1986; Mann, 1988; Reinhardt, 1988). After the TIN is created and the surface calculated, curvature of each side if triangle is tested, and if it exceeds the specified limit (based on the required height accuracy) additional measurement is suggested. Locations of these measurements are marked on the screen until densification step is finished.

Contour measurement is supported with several criteria for automatic on-line selection of contour points during dynamic contour digitizaton. These are: distance, time, and curvature (tube) criteria. Combination of these criteria is also possible.

Standard functions for interactive data manipulations and editing are developed: browse, delete, undelete and attribute changes. All operations are supported by on-line help and designed in a same manner as the rest of the MapSoft functions in order to make training and work as easy as possible. Several workstations connected in a computer network can simultaneously use and update data stored within the common data base.

4.3. DTM creation

Irregularly distributed height points and other height information are dominant in case of data acquisition on analogue stereoplotter which cannot drive measuring mark on the specified position. DTM modelling based on TIN (Triangulated Irregular Network) has therefore been chosen, since it provides very efficient and simple processing of such data.

Triangulation: Several algorithms for the TIN generation have been implemented and tested, each of which respects terrain lines. These are: continuous development of the TIN (McCullagh, 1980), radial sweep algorithm (Mirante, 1982) and point insertion algorithm (Reinhardt, 1988). Each of these algorithms result in Delaunay triangulation with well known properties, constrained by terrain lines. The best results are achieved with point insertion algorithm and it will be briefly described.

Initial triangulation consisting of four imaginary vertices located outside active DTM area is created. After that terrain lines are processed sequentally. If the line length exceeds specified value, then the line is divided. The heights for the new points are interpolated by linear interpolation from the end line points. Each line segment is subsequently processed as a separate line. For each line end points are first inserted into the TIN. Insertion of a point is done by finding the existing TIN triangle that the point falls in. The triangle is after that divided into three new triangles. This is followed by local TIN optimization which is performed until Delaunay criterion is satisfied (Sibson, 1978). When the both line points are inserted, triangulation is again modified to ensure that the line forms edge in triangulation. Whenever possible, swapping of the alternative diagonals for the quadrilateral consisted of the two TIN triangles with the common edge is performed. Otherwise, new point is inserted into the TIN and its height is interpolated using linear interpolation from the end points of the line.

After processing of terrain lines, single height points are inserted into triangulation using the same algorithm. Using this algorithm it is also possible to obtain the TIN with the minimum sum of all distances. To achieve this, only minor modification of the swapping algorithm for local triangle optimization is necessary. Spatial triangle sorting for faster manipulations is perfomed after triangulation is finally completed.

Surface creation is done by finite elements method. Three methods for interpolation and terrain surface presentation are supported: linear, third order and fifth order polynomial interpolation. The simplest and fastest solution is linear interpolation. In that case terrain representation is done with triangular facets. The calculated surface is continuous but not smooth. This is primarily used for initial checks of the data.

For high quality terrain modelling triangular surface patches are represented by high order polynomials. Third or fifth order polynomials can be used optionally.

In each TIN node, partial derivatives are estimated using information on neighbouring nodes (Akima, 1974, 1978). If fifth order polynomial is chosen, then first and second derivatives are calculated. This yields five derivatives for each TIN node. In case of third order polynomial, only three values for first derivatives are calculated. Where breakline exists, two or more sets of derivatives are calculated for each node.

Terms of the polynomial are calculated from the heights and derivatives of the three triangle points (Barnhil, 1981; Sekulović, 1984). The result after calculation and connection of all triangular polynomial patches is a continuous and smooth terrain surface. The only exception is across breaklines where smoothing is intentionally avoided.

4.4 DTM analysis and data verification

The calculated model of terrain surface and the TIN topology are used for all subsequent analysis. These analyses currently include: interpolation of heights, contour construction, fast interpolation of heights in regular grid and profiles, evaluation of DTM quality and calculations of volumes. Only the functions that are essential for primary data verification will be briefly discussed in the paper.

Interpolation of height at specified point is done simply by determining which triangle the point falls in. In case of linear interpolation height is calculated from the condition the point belongs to the triangular facete. In case of smooth interpolation using high order polynomials, the height is the value of the polynomial for that triangle. This operation is supported in on-line mode when MapSoft's cursor is moved across the screen.

Contour construction: In case of linear interpolation contour segments are simply intersections of horizontal plane containing the given contour and triangular facets. In order to get smooth contours polynomial interpolation is used. Each TIN triangle is divided into the specified number of subtriangles. Heights for subtriangle vertices are calculated as values of the polynomial for the main triangle. After that, contour segments are calculated using linear interpolation within subtriangles. Two options for contour construction are available. One of them are non-sorted contour segments. This option is faster, but it only satisfies requirements of on-screen plotting. For additional smoothing of contours using spline functions and for plotting on pen plotters, the option with sorting and connecting of contour segments is required.

Verification of DTM: Visual check of the acquired data can be done by inspecting data distribution, generated TIN or constructed contours. All these DTM elements and results can be plotted at any time on screen or as output on standard plotting devices (Figure 2). Once display of some of these elements is turned on, it remains active until it is cancelled or a new DTM or its product is generated. All standard display functions for zooming and moving are available. Display of MapSoft's entities for horizontal terrain presentation, combined with display of height information is also enabled.

Rigorous analytical check of generated DTM is supported by calculations of differences between measured or known heights at chosen locations and heights interpolated from DTM at the same locations. It is possible to move measuring mark of the photogrammetric instrument and to track in on-line mode differences between interpolated and measured heights. The results can also be written in the report file together with some statistics concerning these differences. The same applies if file with control points is available.

Analysis of the curvature of triangle sides is used to establish if additional measurements are necessary. If a selected treshold depending on the desired height accuracy is exceeded for triangle side, additional measurement is suggested. This is done by marking locations for all such measuremens on the screen. After new measurements being made, a new analysis is performed and so on. Procedure is to be repeated until there is no need for further measurement. Using this procedure, it is possible to obtain more objective results.

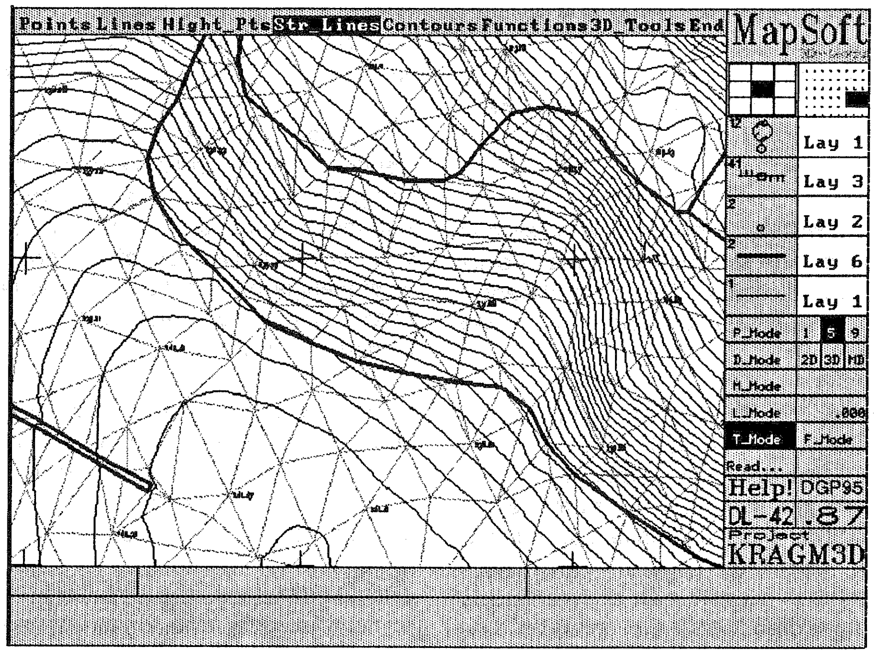

Figure 2 : Visual verification of the acquired DTM data within MapSopft

5. RESULTS AND FUTURE ACTIVITIES

Training of photogrammetric operators is currently going on and the first results are encouraging. Even though it is a quite different approach from direct contouring they are acquainted with, savings in time and accuracy improvements are obvious. Some test areas are chosen for verification of the developed functions and for getting new experiences. Results that can be found in prevous reports (Bill, 1986; Mann, 1988) concerning efficiency (time and data quantity) and accuracy of various data acquisition strategies are confirmed.

Instrumental limitations are the only but considerable factor that lowers efficiency of the system. As far as the software is concerned there are still few things that can be done to improve the efficiency of the system. Further activities on software developments include:

- calculation of optimum spacing for initial coverage of photo model area by systematic sampling (Kraus, 1984);
- development of other functions for DTM analysis: slope calculations, perspective views, etc.;
- total integration of DTM functions and information within MapSoft.

Further utilization of the developed software and new scientific projects will enable determination of the solid criteria for optimum high quality DTM modelling.

6. CONCLUSIONS

The most important functions for support to DTM data acquisition and verification on analogue stereoploters are provided within MapSoft software system. Flexibile data model, support to various data acquisition starategies and the functions for the data verification enable high quality terrain modelling. The same functions can be used for the digitization of the existing maps also.

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