PROGRESSIVE SAMPLING

A new realization of a method for interactive data collection for digital elevation models on analytical plotters

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Abstract

The program was developed on an analytical plotter WILD AC1. The basic points as well as the densification points can be arbitrarily distributed and need not be in a regular grid structure (a mayor advantage of this method). The plotting instrument is driven to the position and estimated height of each point to be recorded and the operator only has to measure the exact elevation of this location. Densification depends on the height accuracy as desired and on the curvature of the surrounding area. Even tops or bottoms are recognized automatically and should be recorded by the operator; at the further analysis a horizontal tangent will be estimated in these points.

Before starting densification, some basic points must be recorded or read into the database from a file. To determine the density of these points, some dense profiles can be recorded first; the optimal interval will be derived by harmonic analysis. Files containing breaklines and structure lines can also be added to the basic terrain information. Points are connected by a triangular mesh. Curvatures along the triangle sides and possible extreme values within the triangles are computed. The densification can be performed in several steps. The more steps performed the closer the accuracy of the compiled DEM approaches the desired accuracy. The program helps the user to measure a DEM more accurately and quickly and saves storage capacity, because the ground surface is optimally described by a minimum of data.

1. Introduction

The idea of progressive sampling, a method of photogrammetric data collection for digital elevation models, was initiated by Makarovic [1,2,3] in the early seventies. The aim was to reduce the amount of collected points compared with conventional contouring, profiling or grid measurement and to increase height accuracy by sampling points only where they are needed for optimum description of the terrain. An initial coarse square grid is densified in several iteration steps by bisection dependent on second elevation differences in both X and Y directions.

Since this regular grid structure is still a restriction to point distribution and there was still a dependence on the coordinate system this method was generalized to an arbitrary point distribution and surface analysis for curvature and local extrema with respect of break lines and structure lines using finite elements. These and some more features were realized by a program developed on a WILD analytical plotter AC1 running on all WILD Aviolyt series plotters AC1, BC1 and BC2. A preliminary version was first presented at ISPRS Congress in Rio de Janeiro 1984 [4]. The latest release has further enhancements, which are described in the following.

2. Program features

The program is fully integrated into WILD's standard system software concerning both user interfacing and data base management. It is called as a data acquisition option after the interior, outer and table orientation have been performed. The program works interactive, completely menu driven and is very easy to use. There are seven main parts which will be descibed in the following:

2.1 Initialisation of height accuracy

Dependent on the distance the between the perspective centres, the height above ground and an empirical value for the accuracy of parallaxes measurement a minimum achievable height accuracy is calculated and three times that value is proposed to the user as default. Any value not less than the minimun is accepted by the program.

2.2 Definition of sampling boundaries

Any convex quadrilateral can be defined by registration of four points in the model and/or input of control points names. New points are stored with their names in the control point file to use them again for adjacent sampling areas either in the same or in the next model. After definition a check can be made which drives the measuring mark in the restitution instrument and the pen of the connected plotter along the four sides of the polygon.

2.3 Definition of a basic grid interval

There must be basic data for surface analysis and densification derived either by measurement of a coarse basic grid or by input of already existant terrain points covering the sampling area into the database (--> 2.4). Both methods can also be used together. By experienced operators the basic grid interval can be input manually or derived empirically by measuring some characteristic profiles in the model. Data collection in these test profiles is very dense and by harmonic analysis and decomposition into Fourier series a basic grid intervall is proposed to the user [5,6,7]. Test profiles should not cross break lines, because that results in unnecessarily small intervals. Break lines and structure lines are taken into account anyway when progressive sampling takes place and need not be considered in the basic grid.

2.4 Input of already existing data

An existing DEM derived from an analogous or analytical instrument or from a data base can be input instead or in addition to the basic grid. Break lines and structure lines should be measured and input if any exist for better accuracy of the final DEM and less densification points during the sampling process. The data points are converted to an internal data base structure for fast direct access during progressive sampling.

2.5 Basic grid measurement

The basic information for the terrain analysis and the densification procedure is a regular triangular grid with the specified basic interval as sidelength. First the boundaries are scanned with that distance and then the points within that limits are measured.

2.6 Progressive sampling

Basic terrain points are densified in several steps dependent on the desired height accuracy and the curvature of the terrain surface. The program automatically builds working units of different size dependent on the local point density. A triangular intermeshing of these points with a minimum sum of all distances is performed. Break lines and structure lines always are part of the triangle network to avoid smoothing or unnecessary densification. Breaklines also build boundaries for the interpolation which results in two ore more pairs of partial deviations in these points. In each mesh point the partial deviations dz/dx and dz/dy are calculated by the elevations and distances of the neighbours. For each triangle a polynomial of third order is used for analysis and interpolation, whose terms are derived from the three elevations and the three pairs of partial deviations in the corners. The triangle sides are tested for curvature and if a certain threshold depending on the desired height accuracy is exceeded, a new point is interpolated and the operator is requested to adjust the elevation of the measuring mark and to release a registration. In addition the interior area of a triangle mesh is tested for a local extremum. For these points partial deviations of zero are assumed for further densification steps. When a densification step is finished, an 'RMS Error' is calcuated by the differences of the interpolated and measured elevations. The operator can decide now if another step should be done or not.

2.7 Data base management

Local data is stored in a special quadtree stucture for fast direct access during the analysis and densification process. Statistics about the number of sampled points and the height accuracies after each step can be shown at any time. There is also a possibility for data editing. Points from the data base can be snapped by releasing a registration close to them. The measuring mark and the plotter pen are driven to the point in position and elevation and the coordinates are shown on the display. Points can be deleted or additional single points can be inserted if desired.

All or only by basic grid measurement and progressive sampling recorded points can be converted to an output file. This output can be done as often as required and at any densification step to achieve files of different height accuracy for different purposes, i.e. for production of orthophotos or calculation of contour lines.

This option also allows˜for complete deletion of the data base after an output file was generated.

3. Operational remarks

The program is controlled by an easy to use menu technique, fully compatible with the AVIOLYT system and application software. Online check plots can be made of all registrations, included boundary definitions and test profile measurement. The operator may exit at any stage. The data registered up to this point is saved and the operator can continue at any time from exactly the same point. Several function keys are available e.g. for changing the z/y components from handwheel to footdisk, for registering or skipping a point etc.

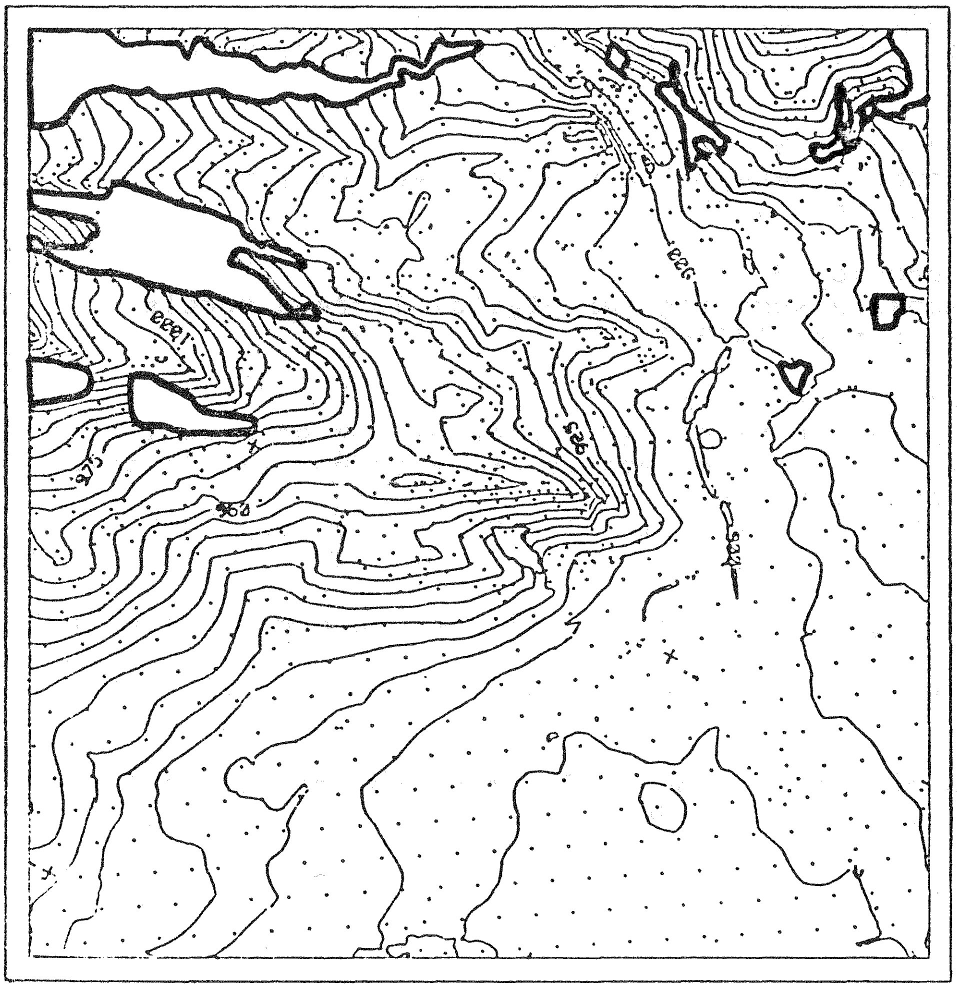
The measuring mark is driven to the predicted point in position and elevation. The operator must now set the floating dot precisely on the ground and record the point. If it is not possible to set the mark another point within a radius specified from the program can be registered. An acoustical signal sounds if the mark is outside the circle, but by use of a function key also sampling of points autside that limit is possible. The operator can always return back to the predicted point by another function key or reject the registration.

4. Discussion of final height accuracy

Several tests with different models were made at the Institute for Photogrammetry and Remote Sensing of the Technical University in Vienna and by WILD Heerbrugg [9] which compared different methods of data acquisition of digital elevation models. A 1000 by 1000 m square area of very rough terrain was measured using conventional grid, profile and contourline methods and Progressive Sampling. The following table presents a summary of results for that comparison.

method	measuring time (h:m)	no of points	accuracy (m)
40m Profiles	0:35	702	1.43
40m Grid	0:21	590	1.49
10m Grid	3:20	9118	0.87
Contourlines	1:57	9290	-
PSA without breaklines (3 steps)	2:46	1577	0.87
PSA with breaklines (2 steps)	2:30	1289	1.13

A comparison of plots of the contourlines with the point distribution in the Progressive Sampling acquisition without these information shows that PSA densified exactly in those regions where the terrain was structured. The time was reduced by more than 20 % and the number of registered points by more than 80 % compared to a 10 m dense grid measurement which lead to the same height accuracy of the DEM.



5. Summary

This solution of Progressive Sampling is based on triangular intermeshing and a sophisticated surface analysis and interpolation algorithm independent form the coordinate system and differs from traditional concepts. Grid intermeshing of the terrain is a common but not a flexible method for data capture in regions with variable relief. The disadvantages become evident when additional morphologic information like break lines and structure lines is to be interpolated into the grid instead of their direct use for the intermeshing procedure. A new quadtree data base structure was developed for storage and very fast retrieval of arbitrarily distributed points and lines for online analysis and densification of the terrain points.

A major advantage is the reduction of time and the number of points to be measured compared with other methods for DEM data acquisition of same height accuracy. Also computing time for programs using that DEMs will be reduced enormously because of less but more qualified input points.

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