

CONTOURS GENERATED BY A DIGITAL TERRAIN MODEL
WITH TOPOLOGICAL TRIANGLE NETWORK FORMAT

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ABSTRACT:

Using a Digital Terrain Model (DTM) to generate profiles, cross-sections, or contours is an impressive approach to civil engineers for increasing their productivity and design flexibility. But the question of how to create a DTM file by stereocompilation for generating accurate profiles, cross-sections, contours or other applications in an efficient manner is of concern to many professionals.

The purpose of this study is to carefully examine the contours created by manual stereocompilation and by the interpolation of a Digital Terrain Model (DTM) in a Topological Triangle Network (TTN) Format, to find an optimal solution.

Through comparative analysis of contours generated with different criteria in a DTM and contours generated by manual stereocompilation, we can approach the most efficient formula for creating the DTM file to increase mapping productivity, without sacrificing the quality of the contours.

KEY WORDS: Photogrammetry, DTM, Topology, Triangle, Format, Contours, Accuracy

1. INTRODUCTION

Using a Digital Terrain Model (DTM) to generate profiles, cross-sections, or contours is an impressive approach to civil engineers for increasing their productivity and design flexibility. The developments of computer hardware and graphic software places DTM applications on a new plateau, such as 3D Modeling, perspective viewing, build-ing road surface, and automatic design. DTM applica-tions have been performing very well on several commercial software packages, the question of how to create a DTM by stereocompilation for generating accurate profiles, cross-sections, or contours in an efficient manner is of concern to many profes-sionals.

Various kinds of DTM formats have been developed for DTM applications, but only the Topological Triangle Network Format satisfies the most of engineers in the requirements of both computer processing and engineering accuracy. The reason is that a DTM, when created with Topological Triangle Network Format can represent the terrain relief with many different features of geographic elements and various densities of terrain points.

Assuming the geographic points are placed in criti-cal locations, the more geographic points available in a DTM, the more accurate the extracted data will be. However, with too many geographic points in a DTM the collection time in stereoplotter digitiza-tion and the processing time in the computer would make it impractical.

There is an optimal number of geometric elements needed to represent the relief of the terrain and still meet the accuracy requirements of the engi-neering project. The geometric elements typically used to create a DTM in Topological Triangle Net-work Format include REGULAR points, BREAK lines, SPOT elevations, OBSTACLE lines, CONTOUR lines, and EDGE line.

REGULAR points are supplemented by random points in an area where there are insufficient geographic

elements to support the accuracy of the DTM sur-face. BREAK lines are the main features used to express irregular topography. SPOT elevations are independent points to present critical locations such as high and low points. OBSTACLE lines are the boundaries of areas that are to be omitted from the DTM. CONTOUR lines are lines of equal elevation. The EDGE line is the boundary of the valid DTM data.

In order to determine the optimal number of geomet-ric elements, we compared the differences between the contours generated from various densities of REGULAR points and the contours compiled by the stereoplotter manually.

2. DESCRIPTION

A Digital Terrain Model (DTM) is a numerical net-work surface which represent the spatial location and the relief of the terrain. The network surface can be expressed with many kinds of formats. The data set commonly stored in a computer to represent a terrain surface is called a DTM data file.

A DTM data file can be created by the following methods:

- 1) Digitizing geometric elements from aerial photo pairs with a stereoplotter.
- 2) Digitizing geometric elements from existing topographic maps on a digitizing table.
- 3) Collecting terrain data with a total station theodolite and data recorder. The recorded data can often be directly converted into a specified DTM format.
- 4) Inputting data from survey field notes using suitable software to convert them into an x,y,z format ASCII file, or a 3D graphic file.
- 5) Converting data from an existing DTM file created by another system.

Several formats have been developed for DTM surfaces. Some of the main formats used in computer software are:

- 1) Grid Format (GRD)
A set of x, y, z digital coordinates that represent the terrain as a regular, rectangular pattern in the x-y plane.
- 2) Triangle Format
A set of x, y, z digital coordinates that represent the terrain using a pattern of equilateral triangles in the x-y plane.
- 3) Triangle Irregular Network (TIN)
A triangle network which represents the terrain using triangles of variable sizes and shapes in the x-y plane.
- 4) Topological Triangle Network (TTN)
A form of TIN network which also represents the terrain with spatial BREAK lines, OBSTACLE lines, SPOT elevations, and REGULAR points to show spatial location and topographic relief.

A TTN file is a data file used to store the Topological Triangle Network data. This file contains all of the input terrain data and the resultant triangle network converted from the topological geographic elements. It is generated according to a designed data structure which uses attributes to store related information about each triangle, neighboring triangles, vertical scale, elevation datum, multiplier and other information.

REGULAR points form triangles under the Delaunay Condition which states that when all triangles in the surface have been formed no other REGULAR point should be contained within a circle prescribed by the three vertices of any triangle. This condition is overridden in the vicinity of BREAK lines, CONTOUR lines, OBSCURE areas, SPOT, and EDGE features in order that no triangle side crosses these features.

For a large project, such as a highway or landfill design, the DTM file is usually created with three-dimensional geometric elements digitized with a stereoplotter and converted into the Topological Triangle Network (TTN) Format. The DTM file in TTN format should be, theoretically, more accurate and more practical than other formats. The TTN format can represent a broad area with a limited number of points defined by variable densities according to the relief of the terrain and the required accuracy of the application. Another advantage is that only the TTN format can model accurately the critical high and low positions, such as road shoulders and ditches, without any additional efforts.

The Intergraph InRoads software, a TTN based DTM modeling and design package, was used to implement experiments which try to find the most efficient method to create an DTM file that meets engineering accuracy requirements. A study area of approximately 2100x800 feet was selected for these trials. The photogrammetric data collection was performed using a KERN PG2 analog stereoplotter interfaced with an Intergraph workstation.

All the geographic elements of the DTM were digitized by the same operator with the same stereoplotter in order to reduce the interference of human and system errors. These DTM files were then used for creating contours, profiles, cross-sections, and for estimating cut and fill volumes for a highway design.

The standard procedures implemented in this experiment were as follows:

- 1) Set up the stereo model and design file;
- 2) Digitize EDGE line (boundary) on a specific level with corresponding symbology;
- 3) Digitize BREAK lines, REGULAR points, and SPOT elevations on different level and different symbologies;
- 4) Digitize random contours for verification purposes;
- 5) Convert 3D elements to TTN file;
- 6) Generate and display contours from the stored TTN file;
- 7) Compare the contours generated from the TTN file with the verification contours.

According to our experience, the REGULAR points take most of the digitizing time. Because the operation time is proportional to the total amount of digitized points, the number of REGULAR points digitized has the greatest impact on the cost. For easy comparison, we digitized four files using the same BREAK lines, SPOT elevations, and EDGE lines, but different densities of REGULAR points. For the convenience of digitizing, we used the vertices of 3D line strings to represent the REGULAR points. (see Fig.1)

The final contours were generated at one foot intervals based on the DTM file with the following specifications:

- 1) 25 FT REGULAR Spacing - See Fig.2
- 2) 40 FT REGULAR Spacing - See Fig.3
- 3) 50 FT REGULAR Spacing - See Fig.4
- 4) 75 FT REGULAR Spacing - See Fig.5

3. ANALYSIS and COMPARISONS

The basic assumptions used in the studies and analysis were as follows:

- 1) This is a relative comparison between the contours generated from different densities of geographic points and manual stereocompilation.
- 2) We are presuming the digitization to be accurate.
- 3) The elevation of an individual point is more accurate than the elevation of the digitized contours.
- 4) Assume the final map scale is 1:600, and it will be used in a highway project.

A field verified survey is needed to evaluate the error in the contours from manual stereocompilation. Without a field verified survey, we assume the manual compilation meets National Map Accuracy Standards.

Table.1 is a list of elevation differences between the contours generated from the DTM data with different specifications and the contours compiled manually. The differences are more uniform as the spacing becomes smaller.

Table.2 lists the number of points for each geographic element in different DTM files. The collection time and standard deviation for each file are also shown. These data are used to create Fig.6 for determining the optimal number of points to collect.

In general, the contours generated with the DTM data are similar to the contours manually digitized with the stereoplotter, but a certain amount of deviation will always exist. The contours generated with DTM data which were created with REGULAR points at 25 FT intervals were found to be smoother and more accurate than the DTM contours from models using a larger spacing. But this increased accuracy may not be necessary to some engineering projects, such as preliminary highway design.

When we look carefully at the comparative contours in Fig.2, we easily see that the contours generated by the DTM data file seem to have some significant discrepancies in the fenced areas labeled A, B, C, and D.

Case in area A:

Some BREAK lines missed in the right hand side of the highway resulted in ditch lines missed in the contours. Fig.3 shows contours generated with DTM data which were created with REGULAR points at 40 FT intervals and enhanced with additional BREAK lines.

Case in area B:

Insufficient REGULAR points could not express the accurate location of the contours.

Case in area C:

This area was covered by heavy forest. The contours digitized by manual compilation and the contours generated by the DTM data were both inaccurate.

Case in area D:

This area was covered by light forest. The contours digitized by manual compilation may be not as accurate as DTM contours.

MANUAL DIGIT. (Elev)	SPACING 25FT (Elev)	Diff (FT)	SPACING 40FT (Elev)	Diff (FT)	SPACING 50FT (Elev)	Diff (FT)	SPACING 75FT (Elev)	Diff (FT)
530	529.94	-0.06	530.77	+0.77	529.88	-0.12	530.49	+0.49
540	539.40	-0.60	540.94	+0.94	540.01	+0.01	540.46	+0.46
550	549.19	-0.81	549.16	-0.84	549.56	-0.44	548.69	-1.31
560	559.78	-0.22	559.51	-0.49	559.83	-0.17	559.97	-0.03
570	570.06	+0.06	570.44	+0.44	571.00	+1.00	571.11	+1.11
580	579.56	-0.44	579.79	-0.21	579.80	-0.20	580.74	+0.74
590	589.95	-0.05	589.18	-0.82	590.02	+0.02	590.27	+0.27
600	599.81	-0.19	599.30	-0.70	599.79	-0.21	598.52	-1.48
600	599.61	-0.39	599.13	-0.87	599.28	-0.72	598.08	-1.92
590	589.50	-0.50	589.60	-0.40	590.02	+0.02	589.73	-0.27
580	579.94	-0.06	580.03	+0.03	580.14	+0.14	580.19	+0.19
570	569.63	-0.37	569.28	-0.72	569.72	-0.28	569.83	-0.17
560	559.82	-0.18	560.01	+0.01	560.00	+0.00	560.15	+0.15
560	559.85	-0.15	560.03	+0.03	560.05	+0.05	560.03	+0.03
570	569.68	-0.32	569.66	-0.34	569.28	-0.72	568.82	-1.18
580	579.75	-0.25	579.42	-0.58	580.11	+0.11	579.59	-0.41
590	589.11	-0.89	589.29	-0.71	589.30	-0.70	589.76	-0.24
600	599.28	-0.72	598.99	-1.01	599.57	-0.43	599.58	-0.42
600	600.01	+0.01	600.02	+0.02	599.81	-0.19	600.09	+0.09
600	600.19	+0.19	599.96	-0.04	600.05	+0.05	600.60	+0.60
600	599.86	-0.14	599.92	-0.08	599.98	-0.02	600.57	+0.57
590	589.95	-0.05	589.98	-0.02	590.42	+0.42	590.07	+0.07
580	579.44	-0.56	579.48	-0.52	579.45	-0.55	579.36	-0.64
570	569.68	-0.32	569.32	-0.68	569.63	-0.37	568.98	-1.02
560	559.47	-0.53	559.51	-0.49	559.65	-0.35	559.02	-0.98
550	549.17	-0.83	549.05	-0.95	548.91	-1.09	549.93	-0.07
540	539.96	-0.04	539.96	-0.04	540.02	+0.02	540.09	+0.09
530	530.33	+0.33	530.63	+0.63	530.35	+0.35	530.53	+0.53
Diff*Diff		4.0459	9.5184		5.2345		15.2552	
Standard Deviation		0.3871	0.5937		0.4403		0.7517	

Table.1 Elevation Differences At Selected Locations.

SPACING FT	REGULAR PTs	BREAK PTs	SPOT PTs	EDGE PTs	TOTAL PTs	TRIANGLES	TIME HRs	STANDARD DEVIATION	REMARKS
25-FT	2954	439	5	170	3568	6883	6	0.3871	
40-FT	1156	439	5	170	1770	3319	3	0.5937	
40-FT-E	1110	575	5	170	1860	3473	3.6		Enhanced
50-FT	713	439	5	170	1327	2439	2	0.4403	
75-FT	313	439	5	170	927	1647	1	0.7517	

Table.2 Number Of Points For Each Geometric Element In Different Files.

4. CONCLUSIONS

The determining factors in deciding what interval to use between the REGULAR points are:

- 1) Purpose of the contour map.
- 2) Relief of the terrain in the area.
- 3) Map scale and contour interval.

If high levels of accuracy are required in specific areas of the project, additional geographic points can be added to increase the accuracy of the data extracted from the DTM in that area. But system errors and human errors may cause irregular errors in the finished contours. Therefore a general guidance formula is needed to guide the operators toward increasing work efficiency and the reliability of the DTM data.

Concerning the reliability of the DTM created contours, the suggestion is to establish a procedure for digitization of geographic elements for the DTM files. It is important to digitize the verification contours on a different layer of the graphic file after all of the geometric elements are digitized. These verification contours can then be compared with the contours generated with DTM data.

From the comparative analysis between the contours generated from the DTM (TTN) files and the digitized contours by manual stereocompilation, we derived the following conclusions:

- 1) Contours created by manual stereocompilation are usually higher than the contours generated by DTM files. Refer to Fig.6, the most of differences between 25 FT spacing DTM and manual stereocompilation are minus.
- 2) Reduction in the density of REGULAR points will slightly reduce the accuracy of the contours if the amount of REGULAR points is still adequate to produce the desired contour interval in the map. (see Fig.6)
- 3) An increased amount of REGULAR points will create contours with smoother curves, i.e. contours expressing more detailed relief.
- 4) BREAK lines play an important role to represent abrupt irregularities in the terrain. If BREAK lines are omitted, it may lead a significant errors in the resulting model. (see Fig.2 A)
If the REGULAR points are reduced, only relatively minor errors will result.
- 5) Digitization of the geographic BREAK lines can compensate for a reduction in the density of REGULAR points. This is a feasible method to enhance the DTM accuracy.
- 6) Unexpected human errors caused the Standard

Error from the 40-FT DTM file to be greater than the Standard Error generated from the 50-FT DTM file. (see Table.1 & Fig.6)

The stereoplotter has been reset for the digitization of 40-FT DTM after the digitization of 50-FT DTM.

- 7) The accuracy of the contours generated with DTM data using REGULAR points at the 50 FT interval were acceptable for highway design.
- 8) More experiments are necessary to set up detailed specifications for the application of DTM data.
- 9) Comparing contours generated from different point intervals and from manual compilation is one of the primary methods to verify the overall accuracy of the DTM data.

DTM applications are not accepted by some professional engineers, because they are reluctant to adopt the results generated from DTM technology. Lack of literature supporting the technical viability of computer software is a major issue hindering widespread acceptance of DTMs within the profession.

The accuracy of the DTM data affects the quality of the results generated from DTM applications. The above method of comparing contours from different criteria can persuade engineers that the results generated from DTM data are as good as the results expected from traditional photogrammetric approaches. Therefore, eventually more advanced DTM applications will be supported and utilized by professional engineers.

5. ACKNOWLEDGEMENT

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6. REFERENCES

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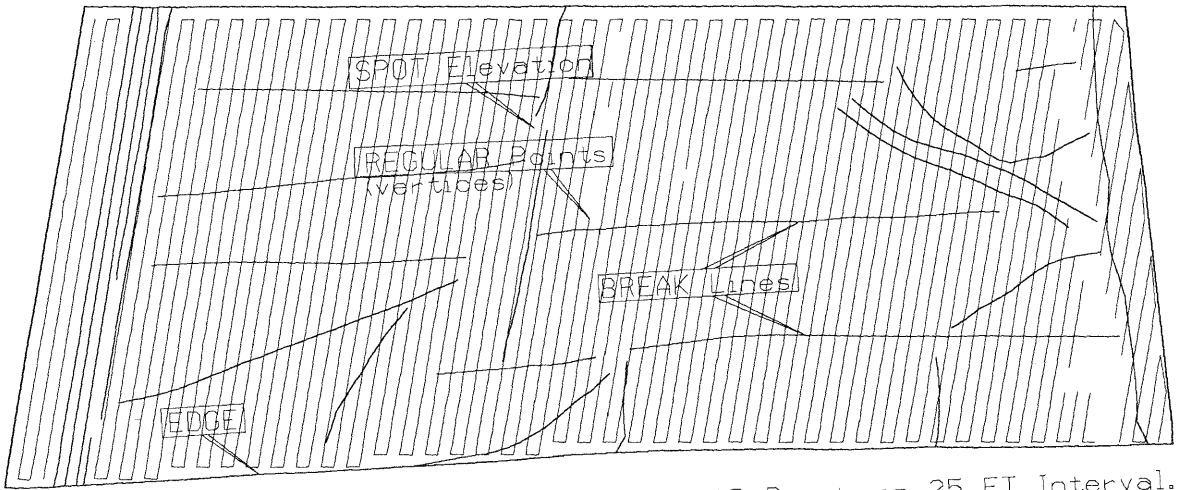


Fig.1 DTM Geographic Elements With REGULAR Points in 25 FT Interval.

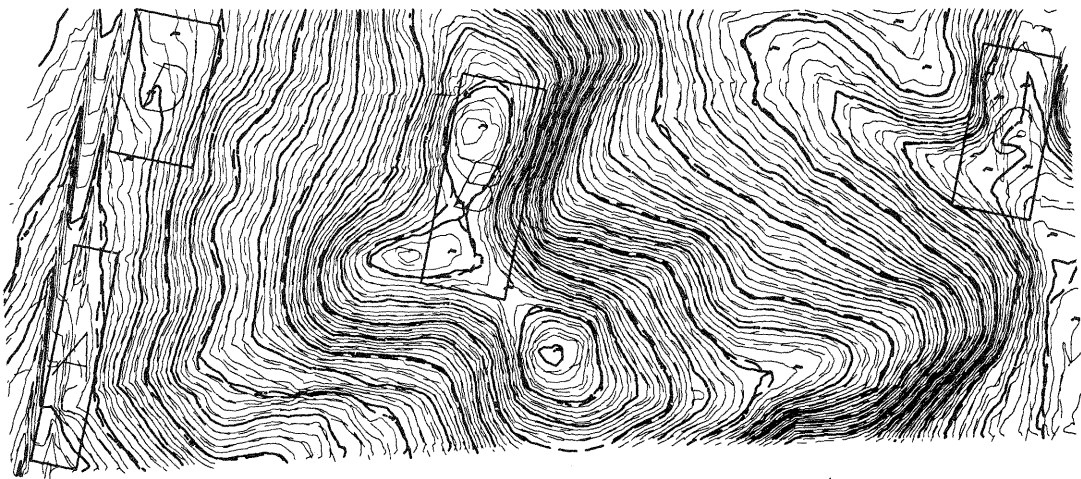


Fig.2 DTM With Regular Points in 25FT Interval

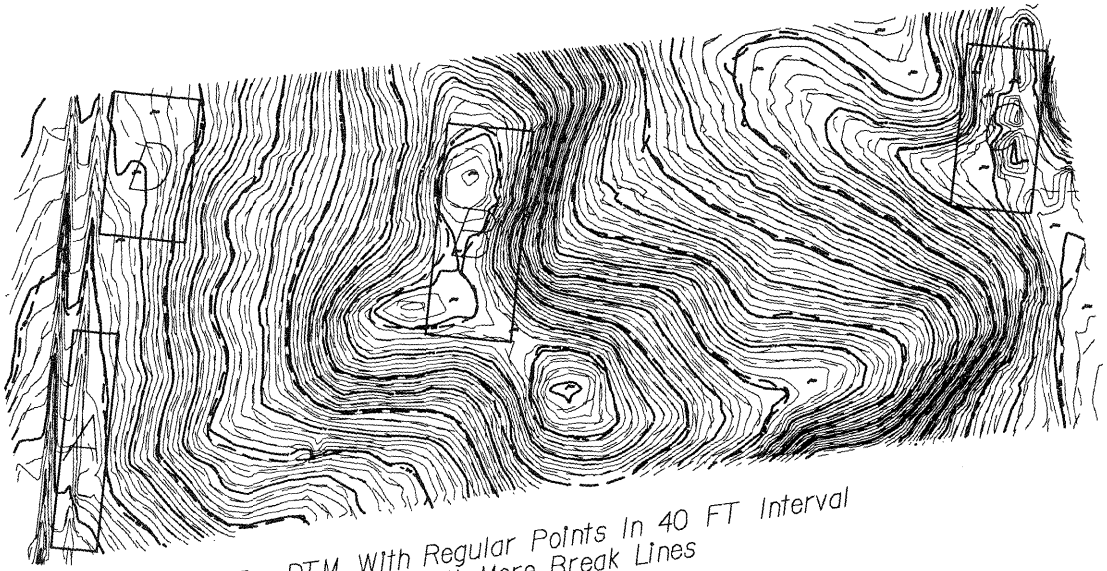


Fig.3 DTM With Regular Points In 40 FT Interval
Enforced With More Break Lines

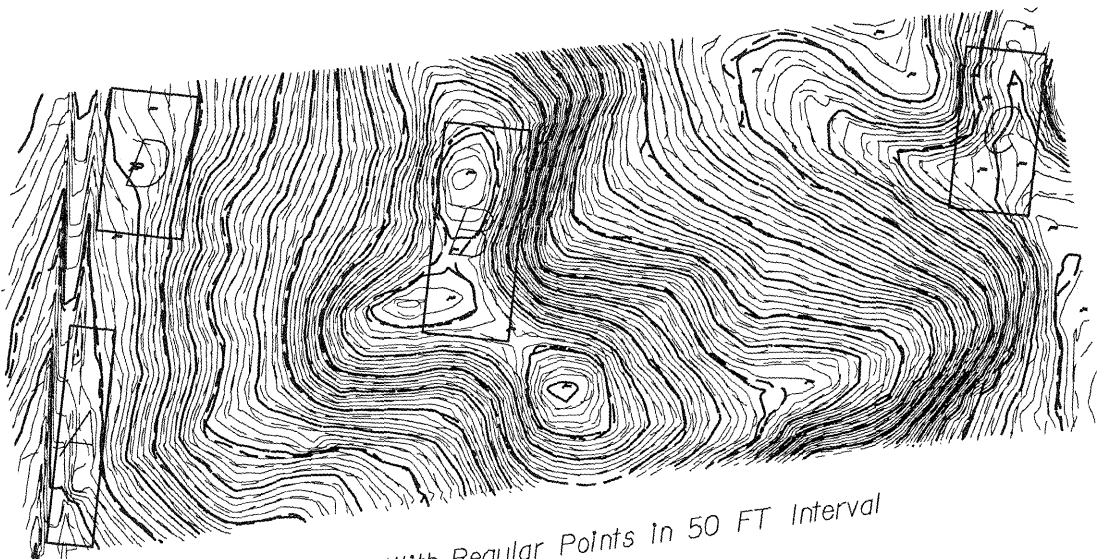


Fig.4 DTM With Regular Points In 50 FT Interval

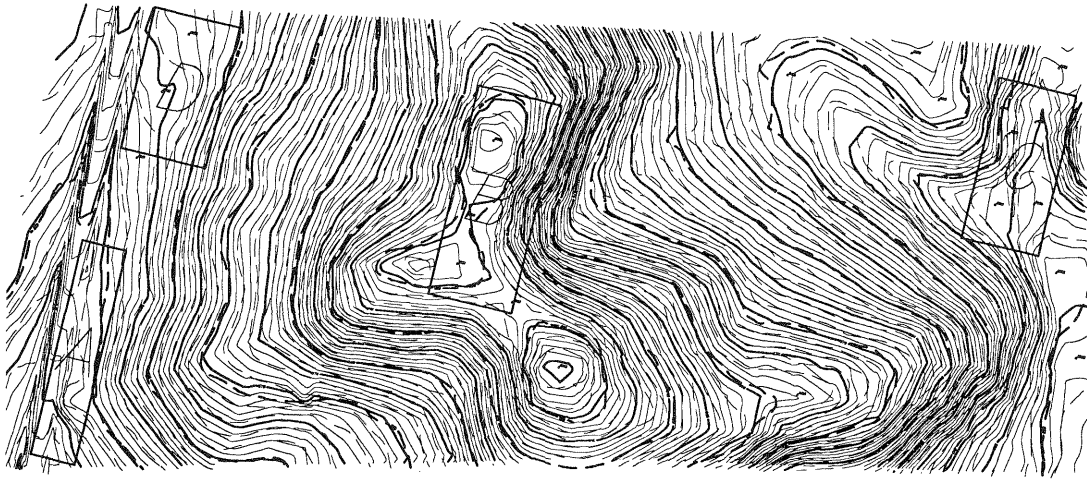


Fig.5 DTM With Regular Points In 75 FT Interval

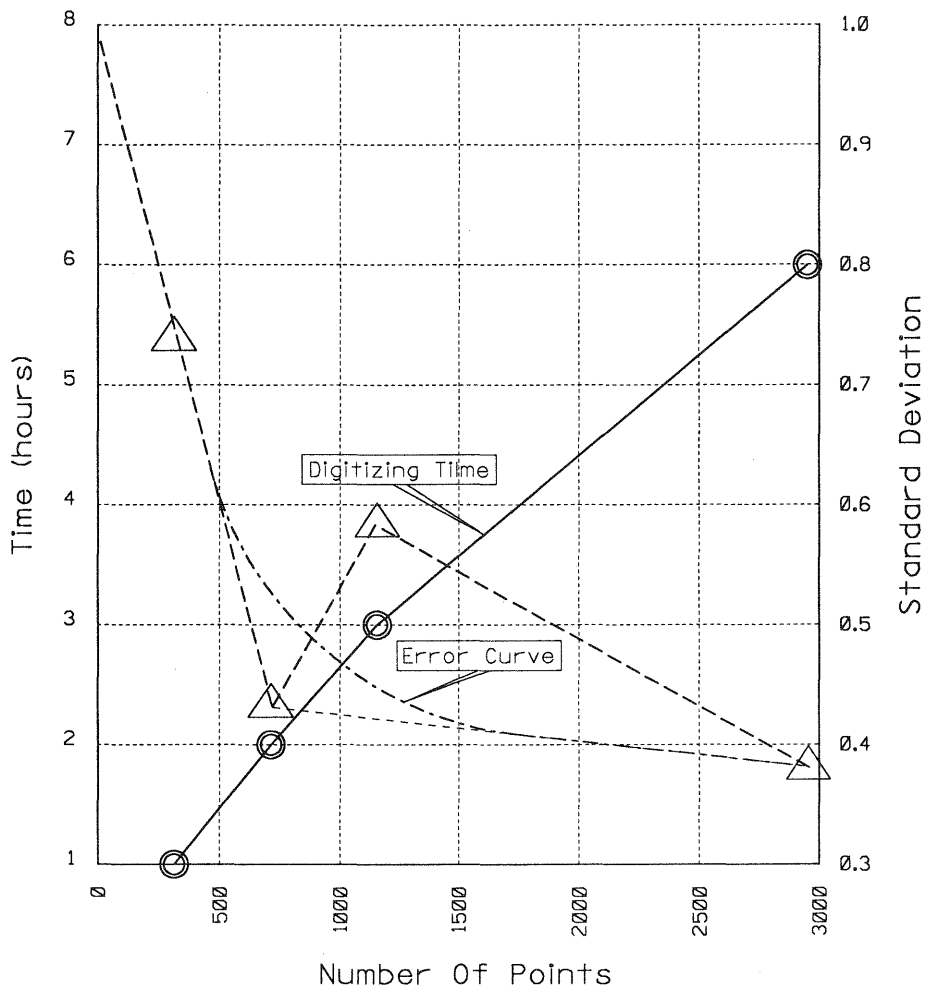


Fig.6 Digitizing Time And Error Curve Via Number Of Points