DIGITAL TERRAIN SERVICES AT CHICAGO AERIAL SURVEY

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1. INTRODUCTION

The concept of computer generating contour lines from X, Y, Z coordinate data has been studied for many years, and a number of government agencies have been computer producing contour lines from coordinate data for a considerable period of time. In the process of evaluating the introduction of computer generated contours at Chicago Aerial Survey, we determined that several deficiencies in existing systems would have to be overcome in order to use the technique for commercial applications.

2. DEFICIENCIES IN EXISTING SYSTEMS

Until now, most existing systems have not proven to be practical for commercial applications for one or several of the following reasons:

Processing Cost. The design of the software required that computer processing be performed on large computers. Since large computers are expensive to operate, the cost of data processing usually exceeded the cost of manually producing contours on stereo instruments.

Accuracy. Most programs were not designed to produce data of the accuracy required to meet civil engineering needs.

Edit Capability. In general, there was limited capability to edit the input and/or output data. Therefore, confidence in the computer generated contours was limited.

Non-Intelligent Input. Many systems required the input of hundreds of thousands of coordinate points. This approach was generally accomplished using image correlators which automatically produced a large volume of data. This required significant edit effort and still did not usually produce the results required for engineering needs.

3. THE CAS SYSTEM

Chicago Aerial Survey (CAS) has implemented technology which makes the computer generation of topographic mapping and engineering cross sections a practical production tool. At CAS, we refer to the services as, "DIGITAL TERRAIN SERVICES". Significantly, the system in use today at CAS overcomes the deficiencies which existed with most previous systems. Specifically, the CAS system has the following advantages:

Minicomputer Processing. All computer processing is performed on a minicomputer which helps make the technique cost effective.

Accuracy. The system is designed to produce contours which meet U.S. National Map Accuracy Standards.

Edit Capability. The system incorporates excellent abilities to edit (numerically and graphically) the input data, intermediate data, and final output data. The graphic data is edited at CAS on an M&S Interactive Graphics System.

Intelligent Input. Rather than generate hundreds of thousands of input coordinate points (many of which can be in error), the CAS system provides for intelligent selection of only those points which are required to accurately represent the terrain.

Accurate Input. Data input at CAS is performed on a Zeiss C-100 Planicomp Analytical Stereo Instrument and/or on analogue stereo instruments which are directly interfaced to the computer. The software is designed to also accept random field survey information.

Multiple Outputs. In addition to computer generating specified contour maps, the CAS system allows for producing other outputs from the input data. Other outputs include different contour intervals and map scales, digital data formatted to Client requirements, and computer generated engineering cross sections. We are also working on producing other outputs.

4. INPUT DATA

The CAS system allows for the input of four distinct types of information. Each type of information is coded to assure proper utilization in the computer processing operations. The four types of input information consist of the following:

General Terrain Data is input which consists of X, Y, Z coordinates in a generalized pattern covering the entire area of the stereo model. At CAS, we input evenly spaced profiles of the entire stereo model. The profile data is not recorded in a scanning mode, but rather as individual X, Y, Z spot elevations.

Linear Features such as the bottom of drains, bottom and top of banks, perimeter of enclosed lakes, and other critical features are recorded as individual X, Y, Z coordinate strings of information.

Spot Elevations are recorded as individual X, Y, Z coordinates.

Planimetric Features which are desired to be computer plotted on the map are recorded as X, Y, Z strings of information. This information will not be considered when computing contours, unless desired. The purpose of ignoring this set of data is to prevent elevation errors in the contour data which can result if planimetric features are not at ground level (such as the tops of buildings, etc.). Therefore, at CAS we do not use the planimetric data when computing contours.

5. CAS COMPUTER SOFTWARE

Software Authors. The basic CAS software was developed by Dr. Benjamin Shmutter and Dr. Y. Doytsher of Israel. Through arrangements with Dr. Shmutter and Dr. Doytsher, Chicago Aerial Survey is assigned exclusive rights to use and license the use of the software in the Western Hemisphere. CAS made the software usable in a production environment and accomplished the interface of the software to the Interactive Graphics System.

Software Design. The software is designed to process on most any minicomputer of 32K memory with a Fortran compiler and disk. The ability to process a large number of complex tasks on a minicomputer is made possible by three measures as follows:

a. Subdivision of the system into a number of individual programs which can be executed in one sequence when called up by a macro program or can be run one after the other at different points in time. The programs communicate via the computer disk.

b. Adaptation of special computational techniques and conducting most of the computations in an integer mode, making it possible to store large arrays in the memory of the computer.

c. Subdivision of the data into zones and sectors which allows the processor to only work with relevant portions of the data at any one time rather than attempting to handle all of the data at one time.

6. COMPUTER PROCESSING

The software is "human engineered" in that it performs in a tutorical mode and guides the operator through the processing. It allows the operator to select options and change general parameters as desired. The software consists of a series of basic programs which perform the following functions:

Input Edit. In order to edit the input, the original general terrain data profiles are graphically displayed on an alphanumeric CRT. The operator calls up each profile, along with the profiles in front of and behind it to view the relation of the three profiles graphically on the CRT. Erroneous points may be deleted. (See Figure 1)

Linear Feature Match. Linear feature data strings are computer matched between stereo models. (See Figure 2)

Data Subdivision. The data is analyzed by the program and, based on general parameters and the number of input points, the area of the map or model is subdivided into zones, each zone being defined by a variable number of grid lines determined by the computer memory limitations. (See Figure 3) This allows the processor to concentrate on only the data required to process each zone.

Selection of Relevant Points. The program identifies the input points which are located near each grid intersection and analyzes those points for relevance. The irrelevant points are not considered when computing the elevation of grid intersections. (See Figure 4)

a. For example, a grid intersection near the base of a cliff would be distorted if elevations at the top of the cliff were considered when computing its elevation. The use of linear feature coded data allows the program to recognize the irrelevant points. The program will not cross a linear feature line when computing grid intersection elevations. (See Figure 5)

b. The program also considers the relative distance of each point from the grid intersection and considers a point to be irrelevant should its distance be significantly greater than the other points. (See Figure 6)

Illegal Elevations. After discarding any irrelevant points, the program selects the relevant points which are to be used in computing the grid intersection elevation (usually 5 to 6 points). The program uses only those points which are close to and evenly distributed around the grid intersection. If there is insufficient data to compute an accurate elevation, the program assigns an "illegal" elevation which flags the point for edit. An "illegal" elevation is usually caused by either: (1) insufficient number of input points or (2) lack of an even distribution of points around the grid intersection. (See Figure 7)

Computation of Grid Elevations. Computation of the grid elevation is accomplished using a unique method which is not linear and which does not use polynomials. The program constructs a polygon and reduces the area of each surface of the polygon to the smallest possible size. The computation is performed by simultaneous equation, resulting in a rigid mathematical solution. This unique approach solves many deficiencies which existed with previous programs and results in accurate elevations for the grid intersections. (See Figure 8)

Processing By Sectors. In order to compute the positions of contour lines with limited computer memory, the map is divided into sectors, each sector consisting of an area covered by up to 10x10 grids. The program processes each of the grids, one at a time, in a predetermined order and establishes where each contour crosses each grid. Computation is by linear interpolation. (See Figure 9)

Subdivision of Grids. Where linear feature strings of data exist, the program divides each such grid of such sectors into smaller grids, each 10x10 in number and each meshed within the larger grids. This procedure allows for accurately representing the terrain where changes in grade slope occur. (See Figure 10)

Matching Between Models. The system performs matching between stereo models and allows for windowing-out of individual map sheets. (See Figure 11)

Numbering of Contours. Numbering of contours is accomplished by simply specifying that the index contours shall be numbered at a desired spacing (such as every eight inches, etc.). Should a contour number fall on a linear feature line, the program automatically changes the spacing so as not to overprint a contour turn-back, etc. The direction of the contour numbers is automatically determined by the direction of slope of the terrain. That is, the contour numbers are always plotted so that they are readable looking uphill. This feature makes it possible to determine the value of intermediate contours and the direction of slope by viewing only one contour number. (See Figure 12)

7. SUMMARY

The system used to produce Digital Terrain Services at Chicago Aerial Survey makes use of new, innovative technology and techniques. The system effectively combines advanced hardware and software (Zeiss C-100 Analytical Stereo Instrumentation, M&S Interactive Graphics System, and new unique software). Significantly, the process is proving to be a practical and effective production tool for generating topographic information for commercial applications.

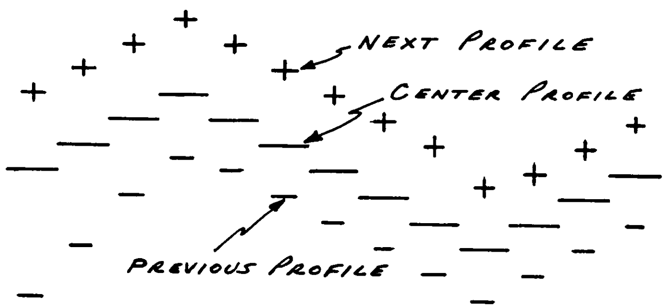

Figure 1 - Input Edit

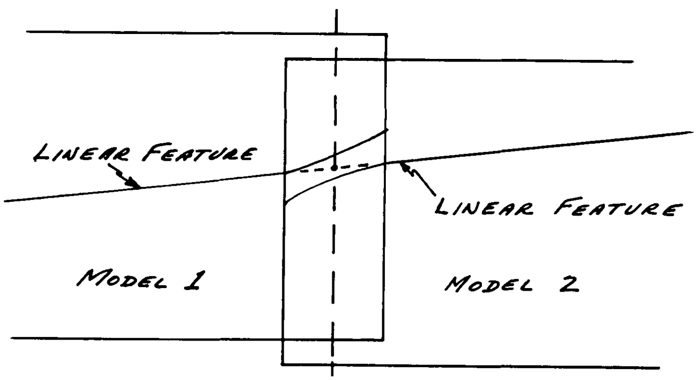

Figure 2 - Linear Feature Match

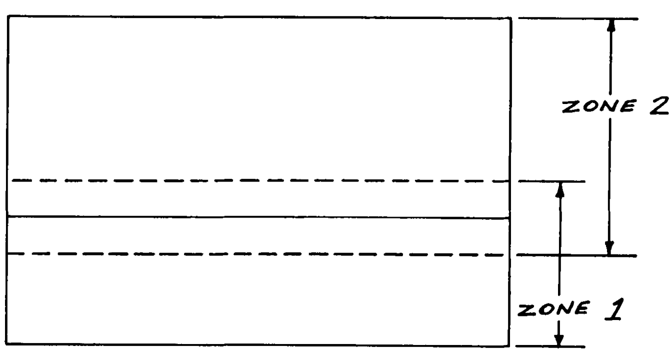

Figure 3 - Data Subdivision

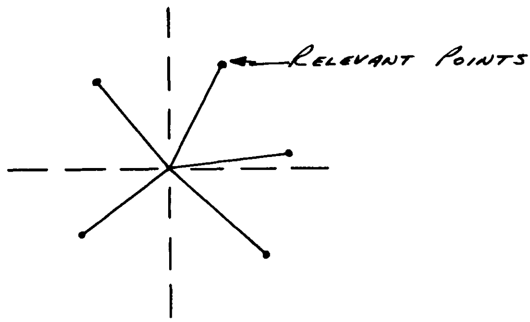

Figure 4 - Selection of Relevant Points

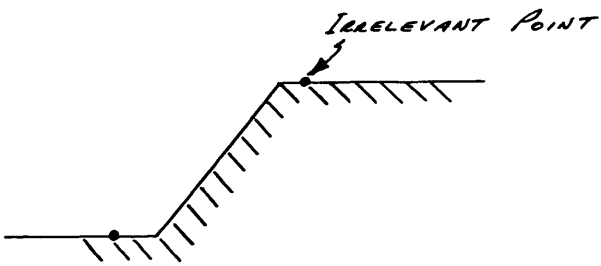

Figure 5 - Irrelevant Points

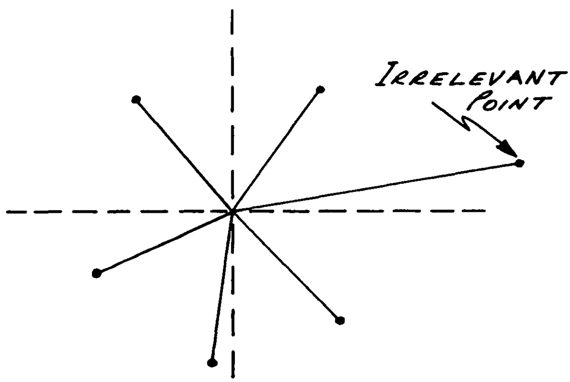

Figure 6 - Irrelevant Points

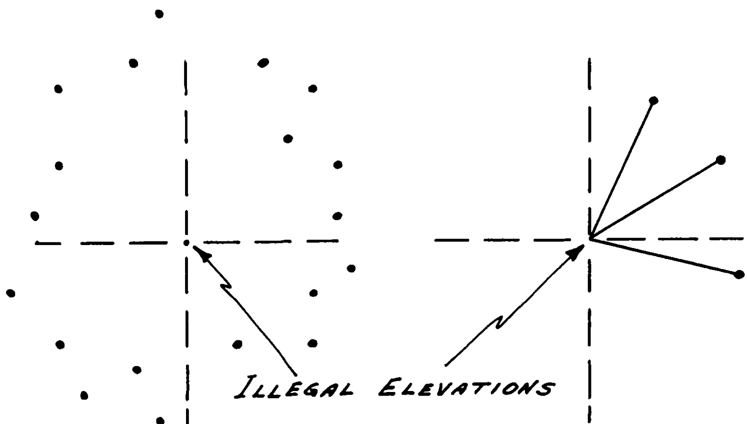

Figure 7 - Illegal Elevations

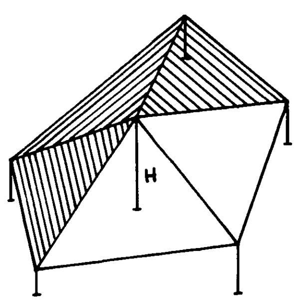

Figure 8 - Computation of Grid Elevations

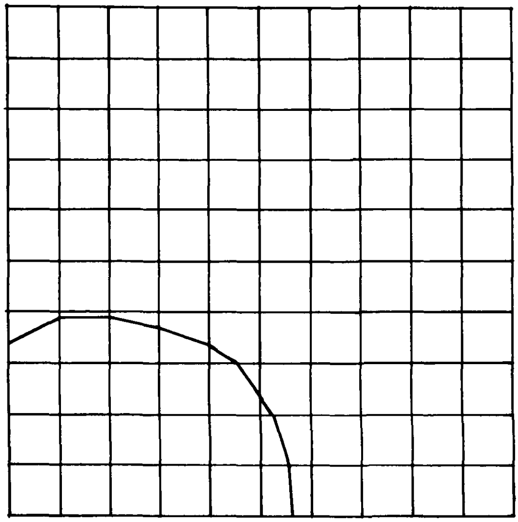

Figure 9 - Processing by Sectors

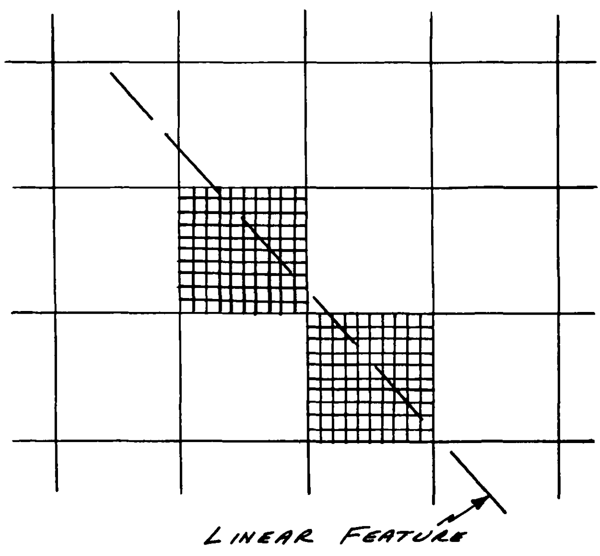

Figure 10-Subdivision of Grids

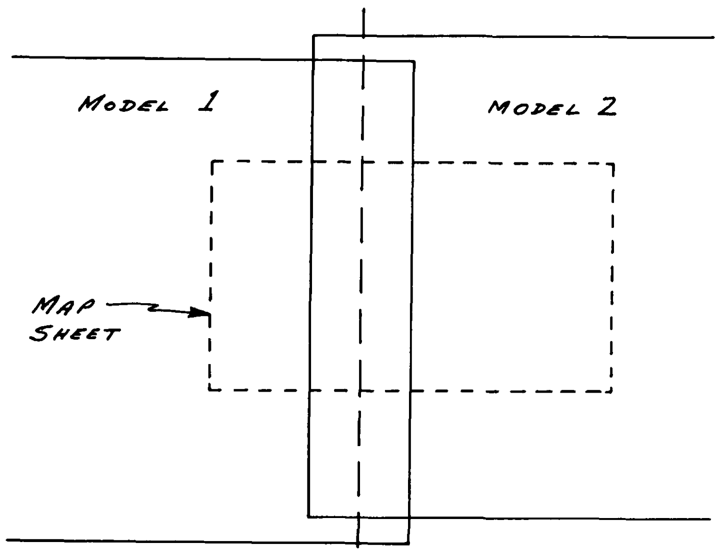

Figure 11-Matching Between Models

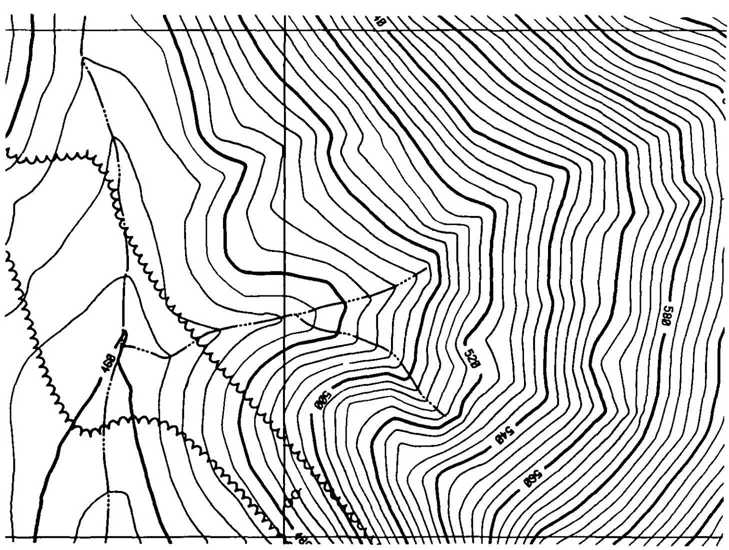

Figure 12-Numbering of Contours