COMPOSITE SAMPLING
USING A MINICOMPUTER SUPPORTED ANALOGUE INSTRUMENT

Huurneman,G.
Tempfli, K.
ITC, The Netherlands
Commission II (WG II/1)

ABSTRACT

A system for semi-automatic data collection for digital elevation models (DEMs) has been developed at ITC. An analogue stereoplotter (Planimat), equipped with rotary encoders and step motors, is interfaced with a minicomputer (PDP 11/45). Distinct terrain features can be digitized in different modes. They supplement incomplete grid measurements. The local grid density is progressively adapted to the variations of terrain relief. This is achieved by near real-time analysis of previously measured elevations and synthesis, i.e., selection of further points to be measured. Positioning of the X and Y carriages of the analogue instrument is computer-controlled (optionally also approximate Z positioning). The paper describes the hard- and software components. Properties of the system are outlined along with some proposals for improvement, extension and alternative system components.

INTRODUCTION

Composite sampling (CS) is a method of photogrammetric data collection for DEMs, in particular for large scale applications [1],[4]. The objective of CS is to obtain,using a time efficient process, precise and comprehensive terrain relief data in a favourable structure. CS unifies selective sampling (SS) and progressive sampling (PS).

The basic principle of PS [1],[2] is iterative grid densification. Initial coarse sampling is followed by data analysis in near real-time, which permits synthesis for finer sampling.The result is a square grid with variable density,locally adapted to the fluctuations of terrain relief. Data are captured and stored per patch, a subunit of the stereomodel area which is specified prior to sampling. Measuring is stationary; X,Y positioning is computer controlled, whereas height setting and triggering of recording is left to the operator.

To increase the efficiency and reliability of PS, it is preceded by SS. Distinct surface features are sampled; these are breaklines and -points,and boundary lines of "anomalous regions" (clouds, water surfaces, dense forest, areas of poor stereoscopic hold, highly irregular and extremly regular surfaces). SS requires photo-interpretation. The data are acquired per model, in dynamic or stationary mode depending on the type of feature, and are stored in vector format. Following the integral approach of CS [3], the selectively sampled terrain features are converted to raster format and partitioned to patches. They are utilized in PS for analysing local relief variation.

To study the feasibility of CS, a prototype system was developed, under the condition that equipment components available at ITC in 1975 should be integrated. At that time we did not have an analytical plotter. To meet the specific requirements, the following hardware components were chosen: The precision analogue stereoplotter Zeiss Planimat D2 and the minicomputer PDP 11/45. The latter supports several other instruments. The Planimat was fitted with rotary encoders and step motors for the three model coordinate axes. The feed-back loop interfacing of computer and stereoplotter was realized by the "Planimat Controller", which was built in-house. Communication between the operator and the system is via an alphanumeric terminal and a foot/hand switch. Software had to be developed for the following functions:

- I/O handling of the terminal
- control of recording in stationary mode operation
- control of recording in dynamic mode operation with a preselected time or distance interval
- control of positioning the X,Y,(Z) carriages of the Planimat
- data collection and storage in SS
- vector to raster conversion
- data analysis, synthesis, and storage in PS
- error detection
- data conditioning for the data base and further processing.

An overview of the system architecture is given in fig.1

HARDWARE

The essential elements of the three subsystems, i.e., PDP, Planimat, and Controller, are listed in table 1.

PDP 11/45 system		Planimat system		Controller
Monitor	DOS	Planimat		Counter cards
Memory	56k bytes	Encoders	Rotary	Motor drivers
Console	VT100	Motors	Step	Control cards
Disk unit	RK05	Terminal	VT100	I/O registers
Magtape unit	Kennedy	Foot/Hand switch		
Interface	DR11-C			

Table 1: Hardware components

The terminal is placed next to the Planimat. It is used to select the mode of operation, enter sampling parameters, encode features, and interrupt/restart and stop operation. Both the foot switch and the hand switch have the same function and can be used optionally. They release coordinate recording. The X and Y encoders provide a least count of 10µm in model space. The least count of the Z encoder depends on the height gears inserted in the Planimat. With a gear ratio of 1:1, the Z-count is 5µm in the model system.

When using the gear ratio that is convenient for the absolute orientation of the stereomodel, the Z coordinates are given either in units of 5mm in the terrain system (if the model scale is larger than 1:3000) or in units of 5cm (if the model scale is smaller than 1:3000). The increment size of the Z motor is independent of the height gears. One step of the Z motor corresponds to 5µm in model space. One step of the X and the Y motor corresponds to 10µm.

The DOS (disk operating system) monitor of the PDP 11/45, a single user operating system, could be replaced by the RT11 which is a more recent monitor for PDP-11 systems. The disk unit of the PDP serves as a storage device for software and temporary files. The magnetic tape is used as the data output medium. Programs are initiated on the console.
The DR11-C is the computer's hardware gate to the Planimat Controller. It is a general purpose PDP-11 interface.
Its logic--consisting of three registers (control and status, input, and output)--allows for program-controlled parallel transfer of 16-bit data between a PDP-11 and a peripheral device. The status and control bits can be set by either the program or the peripheral device.

The Planimat Controller counts the pulses of the X,Y,Z encoders and transmits the data to the DR11-C. It also receives data from the DR11-C and sends pulse trains to the X,Y,(Z) motors. The Controller logic consists of three registers (control and status, input, and output) to communicate with the computer, and six buffers (three for the motors and three for the encoders) to communicate with the Planimat. The input register can be linked to one of the motor buffers and the output register to one of the encoder buffers. The control and status register is used to select the buffer and furthermore to indicate that data can be recorded or that the motors are deactivated (carriages positioned). The encoder buffers are filled by means of circuits which count the number of pulses from the encoders. These buffers can be reset to zero, which is necessary when defining the origin of the model coordinate system. The content of the motor buffer is counted down to zero, corresponding to the stepping of the motor. A logic is built in which prevents steps being lost because of inertia. Voltage controlled oscilators progressively shorten the time between pulses after start (gradual acceleration to maximum speed of the motor) and increase the pulse interval before stop (gradual deceleration).

The Planimat Controller is connected to the DR11-C by a 40m cable, necessitated by the remote location of Planimat and computer. The cable consists of 40 twisted pairs of wires with driver- and receiver cards at both ends to avoid internal reflection. These precautions would not be needed if the Planimat were placed near the PDP. In that case, also one terminal (the console) would be sufficient. Six short cables connect the Planimat Controller to the motors and encoders.

SOFTWARE

The hardware-oriented software, i.e., the I/O routines for Planimat Controller and terminal, have been written in MACRO-11 assembly language code, the application-oriented programs in FORTRAN IV.

MACRO subroutines

These represent the software interface between the application programs, on one hand, and the DR11-C and the terminal, on the other hand (fig. 1). Their functions are:

(a) recording of coordinates (ENCOD)
(b) steering the motors (STEP)
(c) writing to and reading from the terminal (KEYBO).

The subroutine ENCOD transfers the contents of the three encoder buffers to specified variables in the application programs. The subroutine STEP transfers the number of steps, computed by the application programs, to the motor buffers. A check is built in to avoid sending new pulses to the motors before ending the current movement. The subroutine KEYBO supports communication through the terminal. It handles the display of information for the operator, data and command entries by the operator, and interrupts. Interrupts are generated by pressing a key on the terminal's keyboard. Selected keys lead to certain actions. The main actions are remeasuring a point or ending a certain type of data collection.

Application programs

The hardware and hardware-oriented software described above can be used for a wide variety of applications. Each requires a specific set of programs. Fig. 1 shows the main modules for CS.

The interactive program "selective sampling" supports the collection and storage of supplementary data (S-data). It controls digitising, coding and indexing of features, and cancellation or storage of data. Options provided are: stationary/dynamic mode, isolated points/strings, open/closed lines, and single/multiple nesting of closed lines.

The S-data stored on magnetic tape can be verified by producing a check plot off-line. For subsequent PS, the S-data are converted from vector to raster format. Output of the batch-type program is a file on disk containing per point of a gridded line or per isolated point: Z, the matrix indices I,J, and the indices of the patch it belongs to. Gridding is done into the finest grid cell used in PS.

The program "progressive sampling" consists of several modules for:

- input of sampling parameters (model limits and patch size, maximum number of sampling runs, threshold for the 2nd height differences)
- filling the patch matrix with the S-data of the current patch
- guiding initial sampling (zero-run, cf.[1])
- analysis of the matrix after a sampling run is completed: the second difference of measured heights is checked against the threshold. Columns and rows are searched for point triplets (cf.[3])

- synthesis for the next sampling run:
  definition of the new grid points and composing the X,Y list such that the tracking path is minimized. Linear interpolation of heights (and approximate positioning of Z carriage) is optional
- listing of boundary data
- recording of the matrix on magnetic tape after a patch is completed.

Flexible operation is offered by facilities such as: not measuring, off-set measuring, remeasuring a point; comparing measured heights with linearly interpolated ones to reduce unnecessary densification; changing the threshold before starting sampling of a new patch. The patch matrix is dimensioned 33 by 33 because of available core memory; thus the maximum number of sampling runs is limited to five. Adjoining and not overlapping patches are used. The patch sequence is first right (X) then up (Y). Data from the previous patches needed for the analysis in the current patch are kept in the list of boundary data.

Detection of suspicious values in the elevation matrices is done per patch in an off-line batch process. Isolated extremes are identified on the basis of 2nd differences calculated for row- and column profiles. Triplets of neighbouring points are tested for sign alternation. If the 2nd differences at a point are of a sign opposite to the sign of the 2nd differences of the adjacent points and if they exceed the threshold, the point is considered as suspicious. A multiple of the average positive or negative 2nd difference of a profile is used as the threshold. The "factor of suspicion" is an input parameter. Output is a coordinate list suitable for input to the remeasure program.
Furthermore, we use profile and oblique plots for detecting observational blunders and omissions during sampling.

The raw DEM data on magnetic tape (vector data and incomplete grid data in a model coordinate system) can be processed by a package of programs operating on the VAX 11/780 computer. They comprise densification to a complete grid by univariate linear interpolation following the sequence of sampling, or by a general bivariate interpolation/filtering routine, transformation to another coordinate system, data aggregation to new units, and format conversions, contouring, relief shading and various graphic displays, volume determinations, and other DEM applications.

EXPERIENCE

(a) Concerning system development and operation:
With relative low investment costs, an analogue plotter could be upgraded to a system with capabilities approaching those of an analytical plotter. We have used the computer-supported Planimat not only for CS but also for other applications with success. Before attaining operational maturity of the system, extensive hard- and software testing was required (cf.[5]). The prototype system contains all basic components necessary for flexible operation. Experience has shown, however, that an extension of the system to include on-line graphic support is desirable.

(b) Concerning composite sampling:
As far as we can judge at present, CS allows efficient aquisition of comprehensive and precise DEM data. An example of the point pattern obtained by CS is shown in fig.2. It refers to one of the test areas of ISPRS working group III/3.
SS has a substantial impact on the time efficiency of CS and the comprehensiveness of the DEM data. Knowledge about the properties of subsequent PS is a prerequisite for appropriately collecting S-data. SS challenges the operator. PS is a relatively monotonous operation, but also from the human engineering point of view it is superior to complete grid sampling. A fully manual Z-control in PS was preferred by some operators to approximate Z positioning by the machine and manual differential control. As can be expected, imprecise measuring (e.g., in forest areas, as in lower right region of fig.2) leads to undesired densification.

In the present program version of PS, gridded S-data are inserted into the patch matrix. Occupied grid points are not available for measuring. This can cause deficiencies in PS, which depend on terrain slope and finest grid spacing. An alternative incorporation of the gridded S-data is still being investigated. Another point of further study is the refinement of the criteria for data analysis and synthesis. For obvious reasons, error detection should be realized on-line during sampling.

IMPROVEMENTS AND ALTERNATIVES

Controller and computer

The prototype system was developed before microprocessors were on the market. A sytem with the same capabilities could now be designed with a microprocessor. The micro could be used in two ways: first as a recorder, transmitter, receiver and buffer device and second for the functions mentioned and additional tasks such as data analysis and synthesis, data conversion, etc. The host computer PDP 11/45 would become obsolete. The main advantages would be stand-alone, high flexibility because of software control of many functions, and no long distances for data transmission. A floppy disk unit would be sufficient for intermediate data storage.

Analogue stereoinstrument and motors

The Planimat has the disadvantage that the moving parts are heavy. Hence powerful motors are required and tracking speed must be relatively low. The X,Y tracking speed,which substantially influences the time efficiency of PS, can be increased when using an instrument with light carriages and a small model space. Moreover, fitting DC motors instead of step motors should be considered. Analytical plotters are most suitable for CS.

Terminal

A graphic display terminal (e.g., VT125) would allow immediate inspection of data and make operation more interesting and convenient (graphics, menu facilities). All hardware components needed for adapting an analogue stereoplotter for CS can be bought today.

Software

Performance and operational characteristics can be enhanced by including manual grid densification during PS [4], by allowing a variable threshold to adapt PS better to terrain roughness and vegetation coverage,and by providing an interrupt option for breaks and on-line graphic display.

Gross error detection after each sampling run would allow direct remeasuring and prevent adulterations in data analysis. In addition, on-line verification of data would increase the operator's involvement in the process, and instrument time would be shortened.

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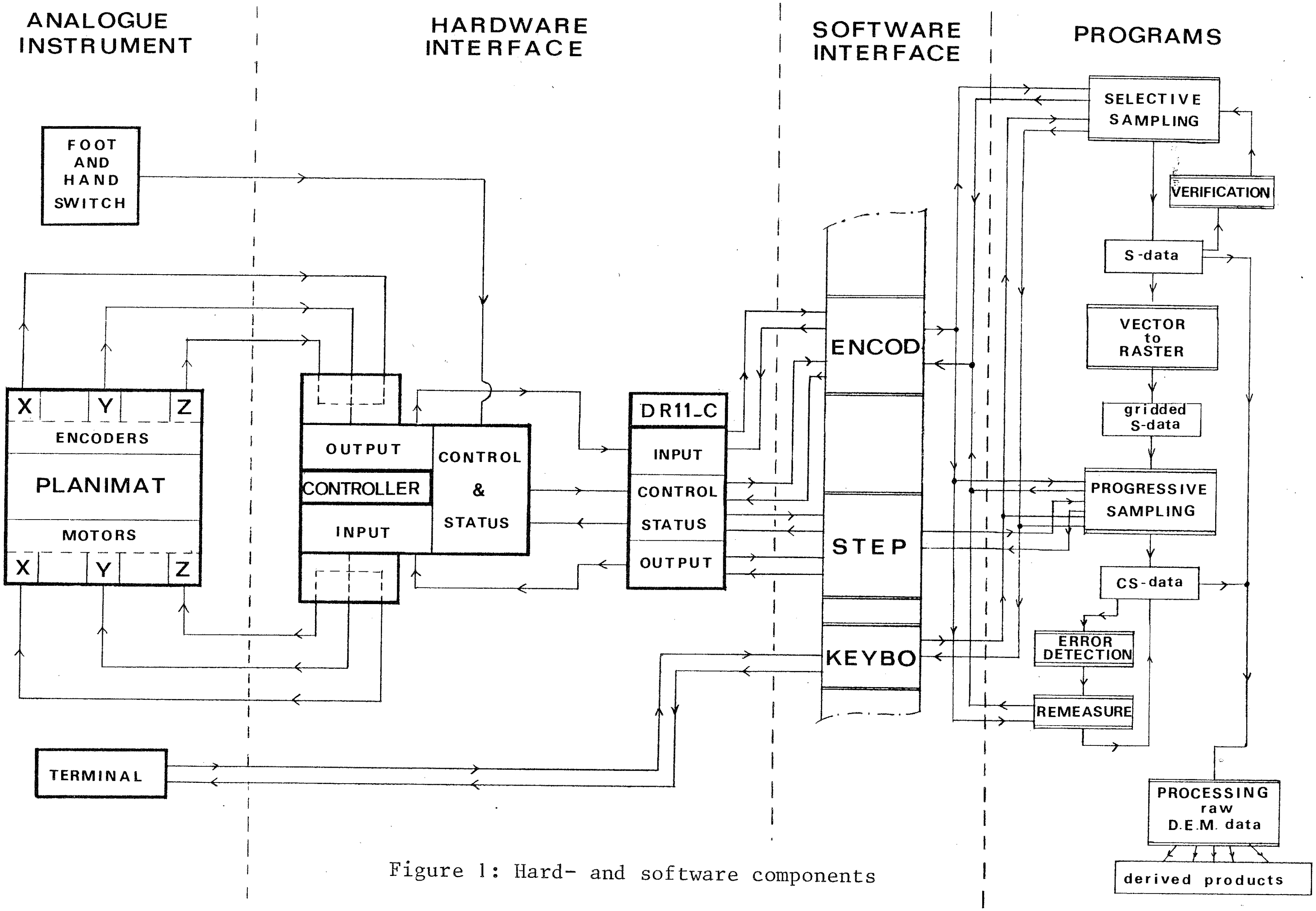

Figure 1: Hard- and software components

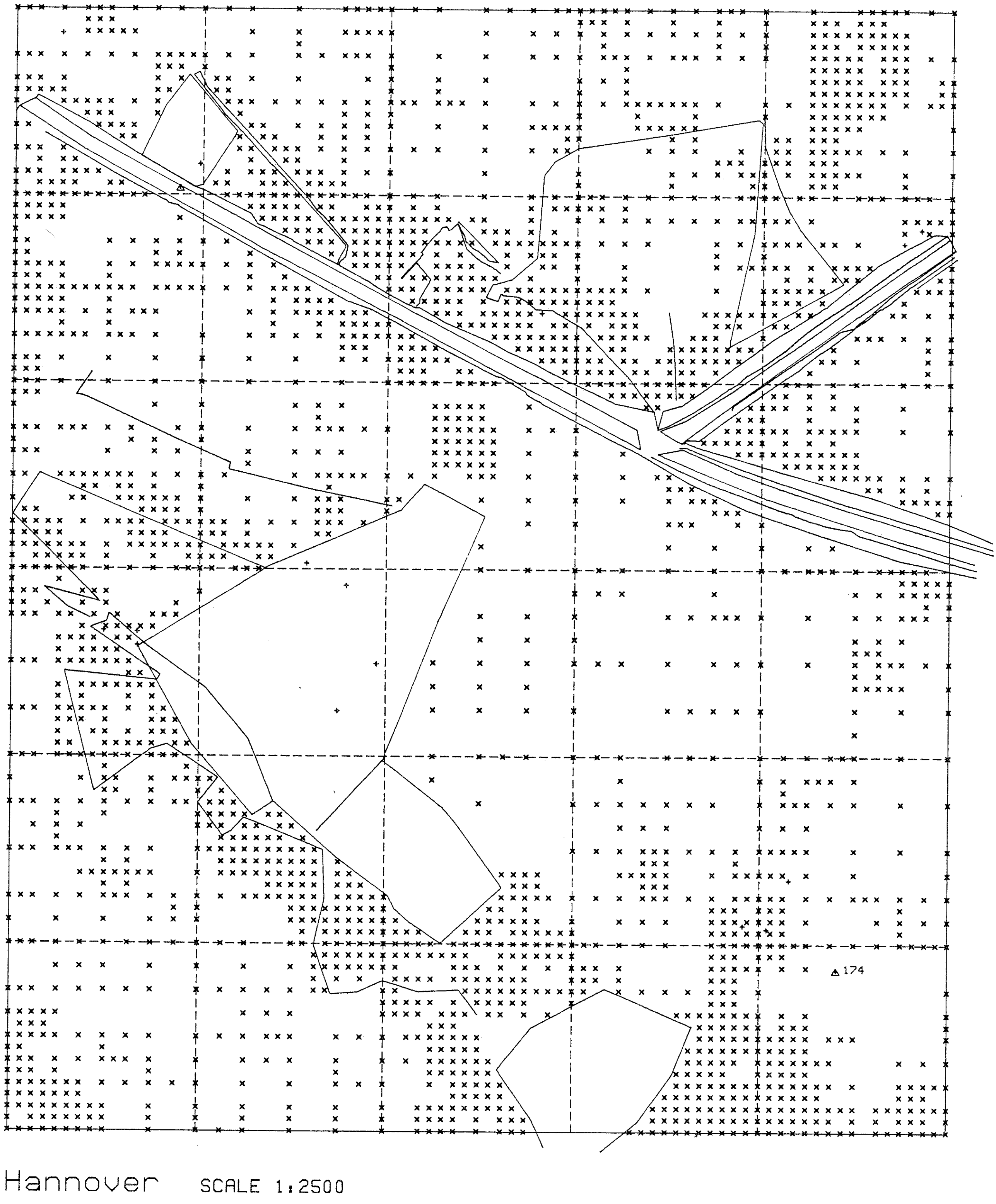

Figure 2: A CS plot