GRAPHICAL DISPLAY AND MANIPULATION IN TWO AND THREE DIMENSIONS OF DIGITAL CARTOGRAPHIC DATA

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ABSTRACT

This paper describes aspects of the work done within Scicon on the use of digital map data, normally displayed in two-dimensional map or chart form, to provide both two and three-dimensional displays and derived interpretations of the map data.

INTRODUCTION

Within both the civil and military mapping organisations digital cartographic data capture, display and manipulation is expanding, such that the creation of digital geographic databases is becoming a prerequisite for the new generation of civil and military communications, command control and information systems.

Scicon's work has been committed to the establishment of suitable databases of this material for efficient retrieval, manipulation and display in both two and three-dimensional form in conjunction with user information of asset deployment. To this end Scicon have produced the product "VIEWFINDER" which this paper briefly describes.

The generation of the three-dimensional information and derived mappings of slope, aspect and intervisibility become available by the combination of contour or randomly sampled height data of the region, with the associated topographic or culture features which make up a conventional map. The following sections highlight the processing of digital map data pertinent to terrain shapes from various capture modes, with the databanking of the culture features for use in a mission planning, communications planning, navigation and asset deployment environment.

1. Digital Terrain Data Capture Sources

In the following paragraphs three sources of digital material will be described which form the basic inputs to digital terrain modelling systems.

Discrete Samples

This source of digital terrain data is the most important and it is to this variety, which the remaining sources reduce during processing.

This type of data is represented by a single triplet of numbers which define the location in three dimensional space, of a point on the surface under consideration.

This surface may be any single valued function which represents a land surface, a sea surface or perhaps an underground surface formed as the interface between two types of rock.

To adequately represent this function, in three dimensional space, the location and height/depth of a suitably large number of points on the surface must be measured, or sampled.

It is important to define the surface with the correct number of sample points, such that:

a) The surface is correctly sampled with respect to the Sampling Theorem.

b) The minimum number of samples are obtained that are necessary from an economic standpoint.

c) The total area of the surface under consideration is sampled at a density (sample/unit area) commensurate with both sampling theorem and economic considerations.

The Sampling Theorem states that the highest frequency, or shortest wavelength components involved in the Fourier Transform of the surface must be sampled at least twice per cycle.

This theorem can be interpreted as saying that if the surface is made up of long wavelengths, eg. rolling hill-sides, then the samples can be taken, on average at a separation less than half the distance between the tops of the hills. If, however, the surface is very undulating and irregular, with very steep sided valleys, then the surface must be sampled at a rate, at least twice per cycle of the shortest wavelength undulations and irregularities that are required in the model of the surface.

Under the constraints of the Sampling Theorem and with a knowledge of the detail that is required on the surface, then the number of sample points required to define the surface can be estimated.

Similarly, the cost per sample, in terms of survey equipment, mapping or photogrammetric resources, man effort, etc, involved in the data collection, can be divided into the available budget, to indicate the number of samples that are possible.

If the budget for data collection does not allow sufficient sample, as dictated by the Sampling Theorem, then the specification of the detail over the whole surface area may have to be relaxed, or the area of coverage reduced.

It is clear that these two factors are in conflict and their implications must be carefully considered prior to undertaking detailed sampling of the surface.

The best known examples of discrete sample points on surfaces are:

a) Soundings on Hydrographic Charts, where the depths of the ocean has been measured at a sequence of sample points taken along the path of the survey vessel, as it moved over the ocean surface. This path may have been organised on a criss-cross basis to provide the sampling rate determined by the considerations given above. This would be typical of a detailed hydrographic survey of an area, or it may be a routine measurement taken of the depth of the ocean alorg the course of a vessel for safety and monitoring purposes.

b) Bore hole data is obtained by mineral prospecting companies in their investigation of sub-strata for oil and mineral bearing rocks.

In each case the resulting information representing the surface is formed from random sampling of the surface in the three axes of the coordinate system, and this is recorded as discrete point information represented at (X,Y,Z) triplets.

i) Photogrammetric Sampling

This source of digital terrain data is obtained via the analysis of photographic images of the surface obtained from aircraft or satellites.

The area being investigated is overflown by a survey aircraft, which takes a series of overlapping photographs of the region. The resulting photographs are, subsequently analysed in stereo viewing systems connected via shaft encoders to digital recording equipment. The human operator focuses the stereo viewing system onto the three dimensional image created by two of the overlapping photographs. By this procedure a particular level, or height value is selected. Then by skilful manipulation of the 3-D image under his view a series of points, of the same height value are identified; as a continuous curve defining a contour line. This procedure is continued until the required set of lines are identified covering the area of interest to the required detail.

This material is captured, in a digital format, as a string, or series of strings of (X,Y) coordinates, all associated with a particular Z value, representing the contour height.

On older photogrammetric equipment, without digital interfaces, map output will then require digitisation.

ii) Existing Contour Maps

This source of terrain data perhaps represents the largest source as a very large number of maps already exist in printed form. The contours on these printed maps have often been created by photogrammetric methods, without the digital interface, and a variety of discrete sampling methods followed by human contour threading to define the shape of the surface.

To convert these existing maps into a digital format requires the process of digitisation. This is achieved using a variety of techniques each of which have associated advantages and disadvantages.

a) Hand digitising - whereby a human follows the contour lines by hand on a flat digitising table, coding each line in turn with its height.

b) Mechanical line following - whereby a laser controlled automatic machine follows the shape of the line and associates the code either automatically or by human voice or finger keying.

c) Scanning - whereby the paper map is scanned in a raster fashion with a flying spot to identify each "pixel" on the map containing contours. These pixels are subsequently converted to vectors and their corresponding height codes associated.

When the contours are in digital format they are again as a string or series of strings of (X,Y) coordinates all associated with a particular Z value representing the contour level.

iii) Conversion of Contours to Discrete Samples

Photogrammetric and digital map data generally occur as line strings of (X,Y) coordinates with an associated Z value for the contour level.

It is necessary to convert these line strings into discrete samples by associating the particular Z value for the line string, with each component point of the line to form (X,Y,Z) triplets.

It can be seen that this form of discrete data point input is formed from random (X,Y) data but quantised Z, to produce the triplets required for further analysis.

2. Digital Terrain Model Creation

VIEWFINDER provides a comprehensive data reduction facility for the class of problems relating to surfaces in a three dimensional space. To use these facilities it is necessary to convert the array of input (X,Y,Z) data points into a more suitable representation of the surface which can be efficiently and effectively processed by computers. The most convenient representation of a surface for such processing is in the form of a set of height values on a uniform square grid distribution.

The numerical approximation, from the irregularly distributed points to height values on a regular grid, provides an efficient and accurate transformation which generates a representation of the surface that exactly fits each of the input data points. This is achieved using a least square error plane fitting technique.

This is based on the selection of the nearest set of, at least eight, sample points distributed in the eight quadrants around the matrix node under consideration. From these points the least square error plane is calculated to pass through the input points from which the value of the node is then interpolated. This process is continued for the whole area to produce the digital terrain matrix.

Uses of Digital Terrain Models

Once the matrix has been calculated it can be used for a large variety of purposes. The following paragraphs give a number of examples, which are not exclusive.

i) Calculation of Contours

From the matrix the shape of the contour figure field can be produced. This can be done by using linear interpolation through the grid cells, or alternatively approximations to a smooth surface that is based on derivative estimates at grid intersections. The latter produces a more desirable result and the validity of the matrix can be checked by this algorithm whereby the contours interpolated from the matrix can be compared with the input data (see Figures 1 and 2). Similarly, the conversion of input contours in feet, to output contours in metres can also be performed.

ii) Calculation of Cross Sections

From the matrix of terrain height, the height at any desired location on the area of interest can be interpolated. This is done by linear or curve fitting algorithms, but instead of computing the (X,Y) position for a given height, as for a contour, the height is calculated for a set of (X,Y) coordinates which define the vertical cross-section, or profile through the surface. Generally only two (X,Y) coordinates are specified, to define a straight line cross section but a number of straight line cross sections can be combined together to define a cross section through the surface, along a curved line.

3. Three Dimensional Views

From the matrix of terrain heights, representations of the shape of the surface can be generated in three dimensional space.

i) Orthographic projection

An orthographic view represents the surface that contains no distortions due to the distance of the point on the surface from the observation point since the eye point is deemed to be at infinity.

Profiles parallel to the X or Y axes are drawn each of constant length (representing the width of the matrix), while the length of the matrix is represented by the set of profiles set back and offset from each other along a line at 45° to the horizontal.

ii) Perspective projection

A perspective view of the terrain matrix produces a three dimensional representation that contains a distortion due to the distance of the object, from the observation point, or eye point.

A perspective view of the matrix looks very similar to the equivalent orthographic view, particularly if there is not a significant difference between the ranges of the set of points on the surface and the eye point.

Perspective views of the surface provide a means of presentation of the matrix information that is particularly easy to comprehend. If the eye point is taken "onto the matrix" then views of the surface that correspond closely with the actual scenes observed from the equivalent eye point on the ground, can be calculated. Compare Figures 3a with 3b which were computed using the Scicon VIEWFINDER Perspective View facility.

Having defined the eye point, it is then necessary to define the direction of view and the angle of the cone of vision around this direction.

4. Line-of-Sight Diagrams

Using the digital terrain matrix, diagrams can be generated which display the area of the ground that can be seen from a particular eye point, either on or off the matrix.

i) Star Diagram

If the location of the eye point is specified in the three dimensional coordinate system of the matrix, as (X,Y,Z), then a series of cross sections through the surface can be calculated. For each of these sections, the (X,Y) coordinate of the eye forms the start point, while the end point is chosen such that radial lines in the X,Y plane from the eye point are generated at a set angular separation for the whole 360° around the eye point.

For each cross section the eye point is positioned at the correct height (Z) and lines of sight from this point onto the surface are produced, thereby identifying the points on the cross section that are visible, and the points that are occluded.

The disadvantage with this type of line of sight diagram is that as the range extends so the resolution of the image degrades.

ii) Intervisibility Matrix

The intervisibility matrix does not exhibit the disadvantage of the Star Diagram, since every node on the Digital Terrain Matrix is analysed to determine if it is visible or not from the defined eye point. Within the VIEWFINDER system the intervisibility diagram is computed for each perspective view simultaneously. Such that a comparison of nodes visible on the 3-D view, with those displayed on the intervisibility plot, provide an easy means of establishing the range of features on the surface from the eye.

Figure 4 shows the corresponding intervisibility plot for Figure 3b.

5. Slope and Aspect

From the digital terrain matrix, the angle of slope of the ground can be calculated and displayed either as contours of constant slope or by colours.

The VIEWFINDER System calculates the maximum angle of slope at each grid node and the aspect of that slope. The aspect of the slope is the direction with respect to North that a sample of liquid would move under the influence of gravity down the angle of maximum slope.

The direction of the colour coded vector indicates the aspect of the slope as measured from the direction of North.

6. Further Discussion of the Use of Perspective Views

Manipulation of Perspective Views

From the above description, it is clear that there are three important parameters to be be defined in order for a 3-D image to be calculated:

a) The eye point
b) The direction of view
c) The cone of vision around the direction of view.

Consider the manipulation of these parameters to advance the use of digital terrain modelling for military applications in general prior to a more specific discussion of military applications which follows in the next section.

i) Change of cone of vision

If the eye point and the direction of view have been defined then the scene in view is equivalent to that obtained by looking through the viewfinder of a normal camera system (see Figures 3a and 3b). If the camera system was fitted with a widely variable focal length lens, or zoom lens, then by changing this focal length an ever more detailed picture would be obtained. The change of focal length directly changes the solid angle viewed through the viewfinder of the camera.

By manipulation of the solid angle around the direction of view the VIEWFINDER system can simulate this widely variable focal length lens, such that the angle of view can been changed from 90° to 1° and a small region of hillside, at a large range, "fills the field of view" of the camera.

ii) Change of eye point

The previous section discussed the manipulation of the cone of vision as a smoothly varying parameter. To follow this philosophy with the eye point, as distinct to stochastically changing the observation point to produce random views, the VIEWFINDER system is capable of generating a connected sequence of views as a simulation of an observer flying or moving via some vehicle over the terrain.

If the sequence of views are presented as a moving picture on film or television, then of the order of 15 to 20 frames must be displayed per second to produce smooth continuous motion.

This requires considerable computing power and other specialised hardware, to generate such animation.

7. Addition of Texture and Culture

To increase the realism, in the computer generated scene, it is necessary to include both the texture of the surface and other details, generally man-made objects, which make up the set of features on the terrain surface.

This requirement necessitates the classification of the various regions of the surface, such as:

- vegetation
  - woods
    - deciduous
    - coniferous
    - mixed
  - crops
    - corn
    - potatoes
    - mixed

- soil
  - clay
  - sand
  - rock
  - silt, etc

Having established the types of surface cover, and their textures, the boundaries of these areas must be digitised, and the facets of the three dimensional view filled in with the required colour and texture, up to the required boundaries.

Much of the data for culture addition to DTMs is acquired from photogrammetric sources but also from vertical or oblique aerial photographs. This is currently a slow and labour intensive process and research is being carried out in a number of centres to automate it. Approaches include the use of artificial intelligence techniques (AI). Only the major simulator companies currently offer any working systems with culture addition, but with the advent of low cost array processors and high-speed graphics devices, these capabilities become available at significantly less cost than full mission simulators.

8. <u>Defence Applications of Digital Terrain Model Techniques</u>

VIEWFINDER is a planning tool which will become an essential aid to intelligence and operations staffs particularly before hostilities, but which will provide increasing assistance during operations as defence forces acquire further ADP capabilities.

<u>Deployment Options</u>

The deployment of friendly forces is reactive to the perceived threat. The elements of surprise available to an enemy indicate that the plans of friendly forces should be secure, effective and flexible. This implies the rapid investigation of several deployment options. In the previous section it is explained how the system is able to interact with queries and demands from the user. This provides the facility for preliminary reconnaissance without the need to undertake a cross-country or helicopter mission.

Provided friendly intelligence has acquired data on the deployment of hostile assets, (primarily, surveillance and target acquisition equipments, and EW sensors), it is possible to identify whether an area is under surveillance or shielded by natural features or culture (woods, buildings, etc). The risk of occupying an area can be estimated and, if necessary, the appropriate responses can be determined: ie. accept the risk if low, eliminate the hostile surveillance, or move to a less vulnerable location.

VIEWFINDER allows the detailed deployment of assets to be made by Commanders before a postion is occupied. For example, the position of a radar site can be adjusted to provide maximum protection of the main lobe consistent with the best coverage of the threat; artillery can be deployed to avoid crest clearance problems; Remotely Piloted Vehicle (RPV) missions can be planned so that the communications links are established precisely when required.

Subordinate commanders can be briefed in detail during a period of tension. Any adjustments to the operation order can be evaluated, enabling the transition to war to proceed smoothly.

Scicon do not consider that any system of this nature can replace the need for a Commander, whenever possible, to view the ground and the environmental conditions which apply currently. However it is believed that preplanning using VIEWFINDER will enable a Commander to confirm his thinking, and to make whatever tactical adjustments he wishes, in the light of the detailed technical assistance at his disposal. This would provide a more cost effective utilisation of time and resources of the Commander and his staff.

During hostilities, VIEWFINDER is available to the planning staffs for preliminary evaluation of other phases of battle, and to operations staffs for real time mission planning. This would provide quicker reaction, a wider choice of options, and greater threat to an enemy via the increased flexibility which sound planning allows.

The following brief descriptions provide specific sceanrio examples of the application of VIEWFINDER to these planning tasks.

i) Sensor System Siting

The deployment of a ground surveillance radar on a terrain feature highlighted on a map will be displayed.

The task of the radar is the surveillance from the top area of the feature of an adjacent road which is visible across the valley.

The problem is to achieve surveillance without compromising friendly radar positions from the hostile EW assets which might be sited on the high ground to either side of the road.

It is essential to protect the radar by its careful siting, and an analysis of the slides which will be shown will provide a number of interesting locations.

The results show what cover is available: light blue is the best area for observation; dark blue the worst. Postions where light blue adjoin black are clearly optimal for both observation and protection from view.

The data derived provides sufficient high quality information upon which to issue deployment orders with realistic six-figure grid references. Tactical adjustment by the local commander will provide the fine tuning on the ground, but this is only necessary over a very localised region of ground.

ii) Communication Planning

The VIEWFINDER system is ideal for communications planning either for securing optimum paths where the use of high ground and relay is permitted or for identifying alternative paths which could diminish the probability of hostile intercept.

In this example, the requirements of a Remotely Piloted Vehicle (RPV) system are analysed. Its mission planning will include periods when it flies autonomously, employing its on-board guidance, also periods when it verifies its flight path by correlation of the actual track with the expected track, and periods when real time transmission is required. In order to communicate with the Ground Control Station (GCS), a communications path must be established at specific intervals in the mission.

Slides will be shown which illustrate:

- RPV mission highlighted on 1:50k map.
- Intervisibility from RPV above target area to potential GCS.
- An oblique 3-D view from RPV to a selected GCS.

It will be seen that the RPV height, the technical requirements of the sensor package, and the ability to shift control from one GCS to another can all be pre-planned with ease. The GCS can be sighted anywhere out of the occluded areas and within friendly territory.

iii) FGA Mission Planning

This example illustrates part of a mission plan for two FGA sorties. Two Harrier aircraft are being used against defended localities. The localities are defended by a surveillance, early warning radar and four SAM 7 missiles.

The slides shown will provide an assessment of the performance envelopes of the AD radar and missile systems, which defines the boundaries of AD protection around the defended localities:

- The radar coverage calculated by VIEWFINDER.
- The coverage of the four SAM 7 sites.

By comparing the two pictures, the optimum route to weapon release, the time at which AD suppression activity should commence, and the escape route post attack can be determined.

CONCLUSION

This paper describes the use of a software package that is independent of host machine and graphics device.

It uses basic map data that can and will be used in the printing process of maps, such that the data used for interpretation, planning and decision processing is the same as printed on the conventional paper map.

The system then provides the user with an interactive planning, and simulation aid for many types of military and civil situations.

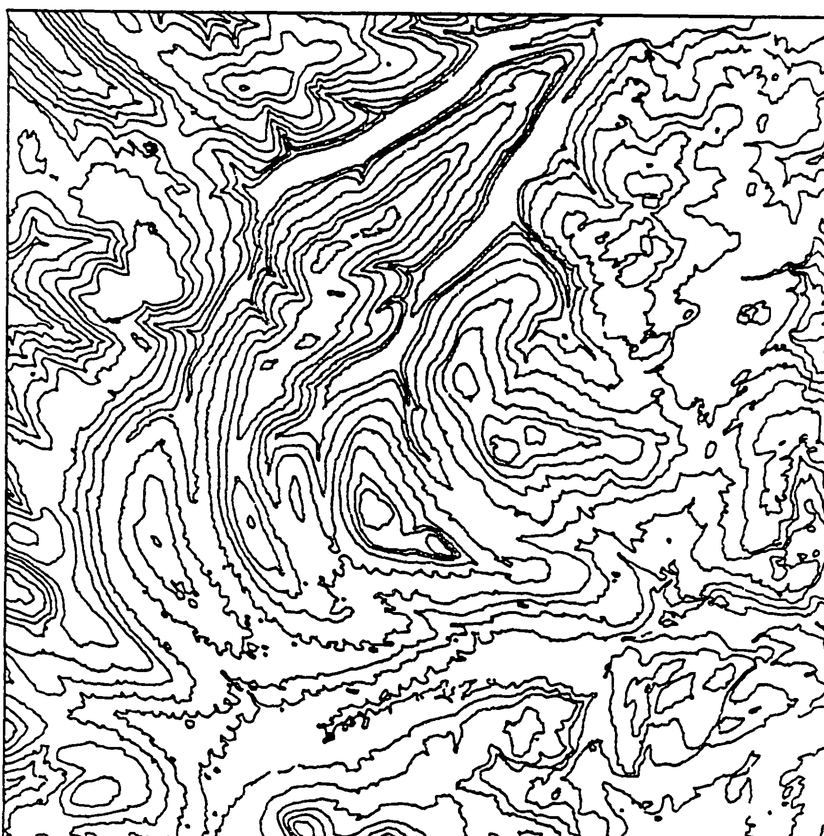

Fig I 50mt Input Contours of 20 kmsquare Area of Yorkshire

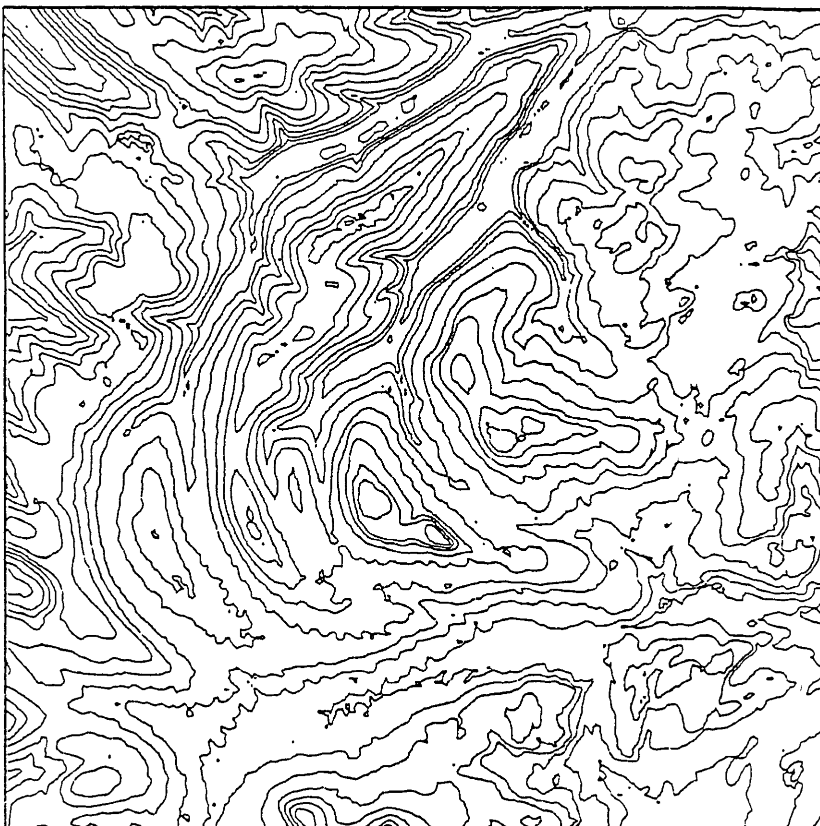

Fig II 50mt Recomputer Contours of 20km square Area of Yorkshire

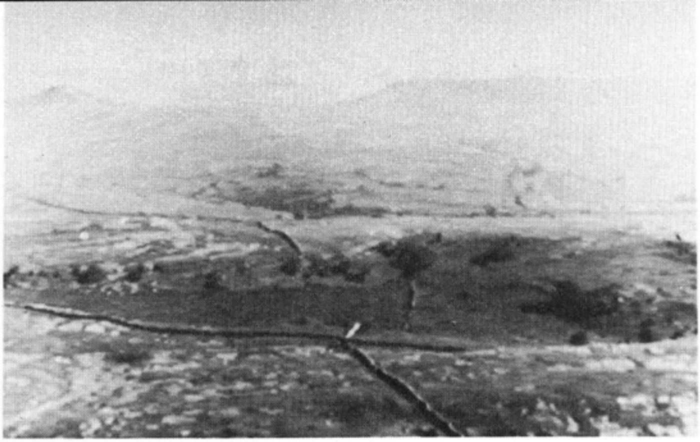

Fig IIIa) Real scene looking N East over area of interest

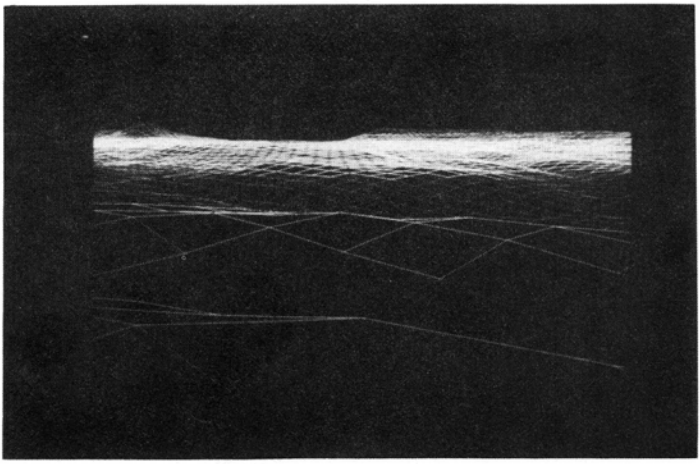

Fig III b) Computer generated scene equivalent to IIIa

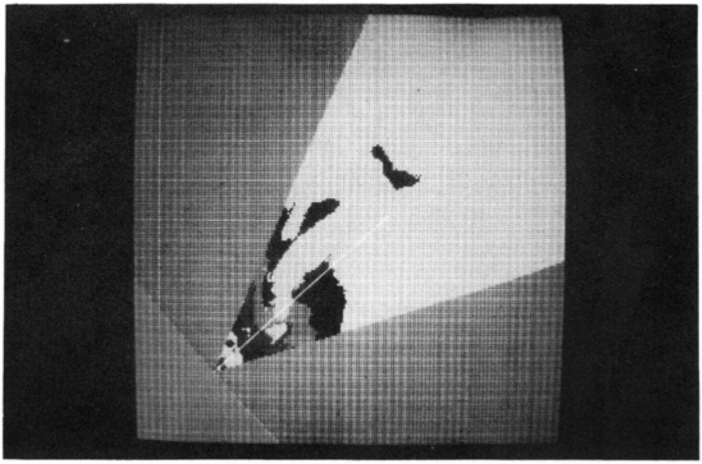

Fig IV Intervisibility matrix showing visible and invisible nodes for Fig IIIa