

Photogrammetric Data Acquisition Using an Interactive Computer Graphics System

The hardware and software of an experimental system for the interactive extraction of digital graphics data from stereo aerial photography is described.

INTRODUCTION

THE COMPUTER has brought a radical change in all phases of production, including the making of maps. New systems are being developed, causing analog procedures to be replaced by numerical ones, and consequently digital processing of data is introduced. Due to this evolution during the last decade, definite progress can be reported in all phases of the map-making process: in field surveys, computations, photogrammetric mapping, cartographic procedures, and map reproduction.

well-defined on a map and interpretation therefore does not play a role. The operator's task consists of following the feature's boundaries and entering its respective code. For the latter several methods exist:

- entering the code manually from the keyboard,
- pointing to the corresponding square on a menu which is fixed to the digitizing table or tablet, or
- actuating special function keys.

Digitizing a photogrammetric model is more complex, as the operator has an additional duty, namely,

ABSTRACT: Acquisition of digital photogrammetric data is discussed. The system used entails interactive digitizing, verified on-line either by a digital plotting table, or by a direct view storage tube. The relevant performance of both of these devices is evaluated. The hardware and software of an experimental set-up based on a Tektronix 4054 graphics system is described in detail, with special emphasis on the user's software developed at the Bundeswehr University in Munich. An explanation is given on the application of visual signals, prompts, texts, and audio signals to maintain interactivity with the operator. Finally, taking into account technological advancement, the trend for future developments is indicated.

The topic of this paper is limited to the photogrammetric field in general and deals in particular with the capture of topographic data, obtained from a stereo model in digital form. During the digitizing process the data have to be prepared and recorded in such a way that consequent processing is facilitated. Solutions are described in the following sections.

PHOTGRAMMETRIC DIGITIZING-STATE OF THE ART

To digitize maps is an easier proposition than to digitize photogrammetric models. Features are

to interpret the features viewed. It is also self-evident that a digitized photogrammetric model needs completion from other sources of information. Part of this information can be incorporated during digitizing, e.g., road classification. Objects which are not visible on the photographs should be added off-line and during the editing stage. Data have to be verified during the process of digitizing, whenever possible. A "fully interactive system" allows the correction of errors in real time. A non-interactive system makes verification difficult and inconvenient.

THE DISPLAY IN THE INTERACTIVE SYSTEM

Both the CRT graphics display and the digital plotting table constitute efficient means of verification during digitizing. For further details refer to Petrie (1980). The advantages and disadvantages of each are summarized below.

ADVANTAGES OF THE PLOTTING TABLE

- The scale of plotting can be so chosen that the smallest details required will appear on the plot.
- The digital table usually being of considerable size, either the whole model or a large part of it can be plotted on one sheet.
- On continuing an interrupted digitization, resetting of coordinates is done on one reference point only, assuring an exact connection between digitized parts. There is no need to regenerate features, because they all exist on the manuscript.
- Each move of the plotting pen reflects a digital signal fed into the processor of the table, a self-checking feature.

DISADVANTAGES OF THE PLOTTING TABLE

- Due to the table's size, the operator sits some distance away. He may have to go to the table for deletions and corrections of the manuscript.
- In large-scale mapping, on completion of a portion of the model, a new manuscript sheet has to be fixed on the table and be oriented.
- During the plotting process the scale of the manuscript cannot be changed.
- The operator has to watch the drawing head of all times, in order to ascertain that the pen is writing.

ADVANTAGES OF THE CRT SCREEN

- The CRT screen can be set up close to the operator.
- The magnification of the display is variable; part of the plot can be zoomed on the screen.
- The plotting speed attained can be very high (e.g., 150 m/sec).
- During the plotting process, lines are drawn on the display as they are digitized.
- On digitizing a new part of the model, or another overlay, the CRT display is automatically fitted to the control.
- The operator can easily discover plotting errors caused by faulty digitizing.

SHORTCOMINGS OF THE CRT

- The relatively small size of the CRT causes most of the difficulties. The display at a large scale contains a small part of the model only, and special care should be taken to assure the continuation of features from one part of the model to the adjoining one.
- The CRT generally is of the "Direct View Storage Tube" (DVST) type which depicts vectors. Parts of the screen in this type cannot be selectively deleted. For editing and corrections the entire screen has to be erased. After the correction of the code and the coordinate values, the whole image must be regenerated. It causes a delay in the on-line process.

- Troubles in the electricity supply cause the erasure of the screen and may also cause the loss of some data.
- Even with the best storage tubes which have a resolution of 4096 by 3120 (13 million) addressable points, lines drawn as vectors have the minimum apparent width of 0.5 mm, which is rather thick.

The type of display, chosen in the early development of a system, usually remains in the latest models as well. Computerized cartographic mapping systems which have evolved from map-digitizing use mostly a CRT display. Photogrammetric mapping, which was formerly used for drawing maps with computer assistance, sticks mostly to the digital drawing table as a display device. However, a number of functioning photogrammetric systems utilize CRTs today. Zarzycki (1978) reports that the Surveys and Mapping Branch in Canada uses a system with several digitizing stations, each consisting of a conventional stereoplotter and a Tektronix 4014 graphics display terminal, supported by a central host computer. Simonsson *et al.* (1980) describe an interactive stand-alone photogrammetric digitizing system, including a Tektronix 4006-1 graphics display terminal connected to a minicomputer. Kölbl (1981) mentions a similar solution, however with a Hewlett-Packard 9845 desktop graphics computer.

AN EXPERIMENTAL DIGITIZING SYSTEM

At the Bundeswehr University in Munich an experimental system has been set up, consisting of the following *hardware devices* (Figure 1):

- Zeiss Planitop or Planimat photogrammetric stereoplotter, having linear encoders for X, Y coordinates and a rotational encoder for the Z coordinate.

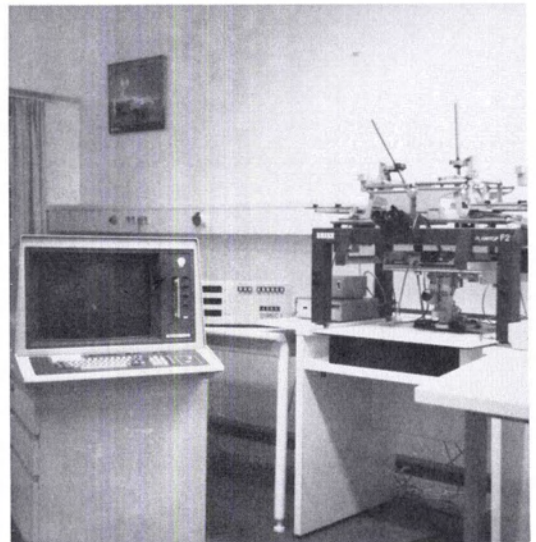


FIG. 1. Hardware for the experimental set-up.

- Direc 1 interface and display for coordinate and code output, manufactured by Zeiss, Oberkochen, in connection with an auxiliary "direc-iec" RS 232 interface.
- Tektronix 4054 graphics computing system, consisting of a 32K Byte stand-alone desktop computer, a DVST with a 48 cm screen, a cassette-type tape recorder having a storing capacity of 300/450K Bytes, a full alphanumeric keyboard, and ten special function keys (programmable).
- Printronix line printer.

The software configuration includes

- A BASIC interpreter included in the 4054 ROM.
- Graphics software with fundamental commands such as Move, Draw, etc.
- A set of programs, written by the authors in BASIC, for interactive digitization.

The philosophy of computer assisted photogrammetric mapping has been elaborated by Dorrer (1977). Applications of this philosophy and extensions to it are described in the following paragraphs.

DIGITIZING MODES

Four digitizing modes are programmed:

- Point objects (symbols).
- Continuous digitizing of lines in distance- or time-mode, including data compression. A suitable interpolation subroutine is used, on-line with digitizing (Opheim, 1980).
- Pointwise digitizing of lines (polygons).
- Closed objects, i.e., buildings.

The digitizing mode is actuated automatically by entering the classification code of the feature.

CLASSIFICATION OF FEATURES

Every feature digitized consists of points which are represented by a pair of coordinates each. The classification code added to these coordinates prepares the data for future processing, be it in graphical or in statistical form.

For the experimental set-up, a classification table has been constructed with a two-dimensional distribution (Figure 2). Horizontally the table is divided into five overlays, i.e., management, land use, water, communications, and utilities. Vertically, four different digitizing modes are represented, as explained above.

The simplest way to enter the classification code would be by means of a menu, fixed on the face of a tablet digitizer. As such, a tablet is not included in the experimental system's hardware; a numerical code of five digits is entered manually through the special push buttons of the Direc 1.

HOUSEKEEPING

The digitized data are stored on magnetic tape by means of the built-in cassette tape recorder. For data editing and processing, complete features are to be extracted. To achieve this, the features are consecutively numbered. A housekeeping code precedes the list of two-dimensional coordinate values. This code includes a right-justified two-digit number (1 to 99), counting the points of the feature. Starting leftwards from the third decimal digit, the feature's serial number appears. As an example, 10597 means that the feature's serial number is 105 and it consists of 97 points.

VISUAL AND AUDIBLE SIGNALS

In order to communicate with the operator, the interactive system transmits visual and audible signals. Messages, prompts, and text appear on the CRT screen in the form of alpha-numeric character strings.

In order to separate graphics from the text, the storage tube is divided by the program in two parts. From the 130 graphical display units (GDUs) available in the horizontal dimension of the storage tube, 110 units are provided for graphical display. The

Classes	DIGITIZING MODE				
	1 POINTWISE	2 CONTINUOUS	3 CONTINUOUS	4 POLYGON	5 CLOSED OBJECT
1 MANAGEMENT	1 Trig. P. 2 Polygon P. 3 Bench Mark 4 Spot elevat. 5 Photogr. P.	1 State Boundary 2 District " 3 Municipal " 4 Village "	1 Undefined Bnd. 2 Special "	1 Wall 2 Hedge 3 Fence	1 Public Bldg. 2 Built-up area 3 Building site 4 Ruin
2 LANDUSE	1 Pine tree 2 Deciduous 3 Shrub, bush 4 Rock 5 Cave	1 Cultivated 2 Pasture 3 Garden/Park 4 Vineyard	1 Pine forest 2 Deciduous F. 3 Mixed " 4 Reforestation 5 Orchard	1 Uncultivated 2 Play & Sports 3 Cemetery 4 Dune 5 Reservation	1 High-rise B. 2 Apartment H. 3 Commercial B. 4 Industrial B. 5 Cottage
3 WATER	1 Source 2 Well 3 Cistern 4 Waterfall	1 River 2 Stream 3 Canal 4 Trench, Ditch	1 Lake 2 Pond 3 Fish-pond 4 Marsh 5 Coastline	1 Bridge 2 Dam 3 Dike 4 Aqueduct 5 Pipe	
4 COMMUNICATIONS	1 Lamp 2 Traffic L. 3 Traffic Sign. 4 Sewage cov. 5 Telephone	1 Expressway 2 Highway 3 District Road 4 Main " 5 Secondary "	1 Railway, sever. 2 " track 3 " single 4 Streetcar	1 Expressway 2 Highway 3 District Road 4 Main " 5 Secondary "	1 Runway, paved 2 " unp. 3 Parking lot
5 UTILITIES & MISCELLANEOUS	1 Wooden Mast 2 Steel mesh 3 Steel pipe 4 Concrete M. 5 Tower	1 Bicycle way 2 Other road 3 Footpath 4 Tunnel	1 Contour line thin 2 " " thick 3 " " dotted 4 Slopes	1 Bicycle way 2 Other road 3 Footpath 4 Tunnel	

FIG. 2. Five-by-five classification table.

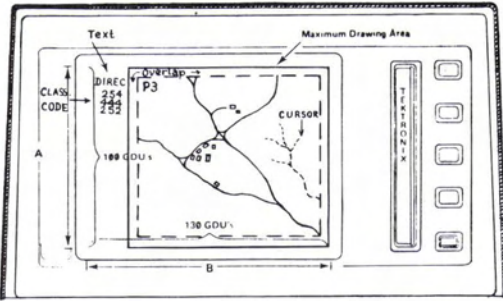


FIG. 3. One third of the model is displayed during digitizing. The refresh cursor appears on the right hand side of the display.

remaining strip of 20 units is reserved for texts on the left side of the screen (Figure 3).

Only one visual symbol is available in *refresh* form on the face of the storage tube; it is used as "cursor." In prompts, waiting for input, a blinking question mark replaces the square cursor. For drawings, plotted on the screen, a conspicuous pointer is needed. In the experimental set-up an arrow symbol, pointing downwards, has been chosen to serve as cursor-pointer (Figure 3).

An electronic bell, built into the 4054 Tektronix console, can be programmed to give off single or multiple audio signals. In the experimental setup each coordinate registration by the foot switch releases a ring of the bell. A double ring of the bell is produced by the program on completion of a line segment, when the operator registers the last point twice, with equal or nearly equal coordinate values. The same happens in digitizing closed objects, such as houses, where the first and last object points should be identical.

When the graphics memory buffer is filled with digitized points, a triple audio signal warns the operator to break off digitizing. Consequently, the program dumps the contents of the RAM onto the internal magnetic tape. On completion of this procedure, the bell rings once again to announce that digitizing can continue.

USER'S SOFTWARE

The program of the experimental set-up presumes that an analog absolute orientation of the model has been carried out. The program enables the operator to check the scale of the model and its fit to the control. The ground coordinates of the control points are entered either from the keyboard, or from a previously recorded tape file. Next, the coordinates of the control points are read in the model.

The program executes a Helmert linear transformation with a least-squares adjustment. The discrepancies dX , dY , and dZ of this adjustment are displayed for each point on the screen; then the operator is asked whether the result is acceptable.

If the operator is not satisfied, two alternatives are given:

- to read the control points again in the model, or
- to try to eliminate the faulty control, one by one.

In each case, a new adjustment is calculated and the newly obtained discrepancies indicate whether the orientation is improved. On accepting the results, the orientation parameters are recorded on tape, in order to be utilized during the data processing phase.

COORDINATE VALUES

Photogrammetrists are accustomed to deal with model and ground coordinates. With the storage tube a third type comes into being, the Graphic Display Unit (GDU) coordinate system. It is an internal unit, dependent on the physical size of the storage tube. One unit is defined as one hundredth of the vertical height of the screen. It is equal to approximately 2.8 mm on the screen of the 4054 (Figure 4).

Prior to execution of any graphics command addressing the screen, the BASIC interpreter of the 4054 graphics system converts all user-defined coordinate values into GDUs.

In the experimental set-up tests have shown that the transformation of model coordinates into GDUs by the user's program does not cause any loss of accuracy, but shortens the execution of graphics commands. For the regeneration of a drawing on the display the time saved by GDUs is noticeable.

THE MAIN PROGRAM

From photo to display a sufficient ratio of magnification is required. A somewhat satisfying proposition is to divide the model into three well-defined sectors, each having the length of the model base.

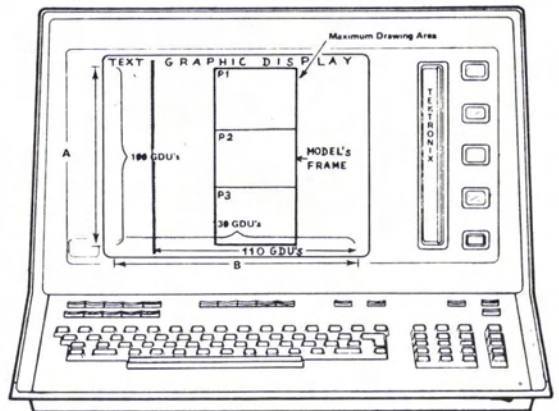


FIG. 4. The division of the Tektronix 4054 screen into GDUs is shown. The model frame, divided into three parts, is displayed in the center. On the left side space for text is indicated.

In this way the proportion of horizontal to vertical dimensions is similar to the physical proportions, width to height, of the viewing screen.

On answering a prompt, the operator reads the four corner points of the model. On completion, the model limits are drawn on the screen as a rectangle. It is divided automatically into three parts, P1, P2, and P3 (Figure 4). Again, a prompt appears on the screen, asking the operator to move the measuring mark into the sector chosen to be digitized first. On releasing a coordinate value, the screen is erased and the newly chosen sector is now displayed, enlarged from the photo scale by about three times (Figure 3). A further development of this main program (Dorrer *et al.*, 1982) improves the display's flexibility considerably.

An important program-feature enables the operator to delete erroneous points during digitizing. Pressing a special function key backspaces the cursor to the previous point, causing the deletion of the bypassed point. This subroutine cannot delete the points on the screen, but on redrawing the bypassed points are omitted.

In addition to the automatic recording of data, executed whenever the RAM is full, a voluntary recording is also possible by pressing a programmed special function key. All the data residing in the buffer are consequently dumped on tape. On restarting an interrupted digitization, the program recalls the previously digitized features from the cassette tape and displays them on the screen. The work can continue forthwith.

DATA MANAGEMENT

Some problems encountered still await an efficient solution. One of them is the unique determination of junction points (nodes). Such a point is common to, at least, two different features. Its coordinates are determined at least twice, but their final values should be unique. The suggested solution makes up a special list of the already existing points and searches this list whenever a node is encountered.

Another problem is posed by the signature of areas. The boundaries of different area objects are digitized as lines. Each segment of these lines separates two different objects. The area classification needs a simple solution. It is intended to add a point symbol together with the classification code, to be placed in the approximate center of the area. It is still not decided whether this point should be added during the digitizing, or on editing off-line. The recognition of areas or regions must be made dependent on the nodes.

TECHNOLOGICAL ADVANCE AND THE TREND FOR FUTURE DEVELOPMENTS

Technologies, already available, promise to make the digitizing process easier.

The method of Automatic Speech Recognition (ASR) can free the operator from interruptions of his stereoscopic viewing of the model. The pressing of push buttons situated at a distance from the operator will not be required any more; instead, a command expressed in common language will be translated by the voice recognition module into the code required by the program.

Another innovation, introduced into the Tektronix system, is the refreshing of selected features. All the prompts and text, which have to appear on the screen for a short period of time only, can be in refresh mode. The same applies to symbols which are used to assist the operator during digitizing. An example is the cross-symbol indicating erasure of an object during editing. Another application of the refresh option is its use as a real time "first-in-first-out" buffer of digitized features. Using the refresh option described, the filling up of the display with text can be avoided.

Auxiliary Memory Modules recently introduced on the market (TransEra; Tektronix) excel in the rapid storage and transfer of batches of data. By its means programs can be extended during processing and the display of graphic data is speeded up. For example, the generation of 500 vectors on the display, which in the ordinary way takes about 7 seconds, can be shortened to 2 seconds by applying a special "MPLOT" command.

Alas, technological advances have a high price. The original experimental set-up, excluding the photogrammetric plotter, cost about \$20,000. Introducing the new features, as mentioned above, will more than double this price.

The functioning experimental set-up is still under development. It is expected that, on gaining experience in photogrammetric data capture, further improvements in technique and programs will be reported on (Dorrer *et al.*, 1982).

CONCLUSIONS

Although the experimental set-up is still under development, the flexibility of the system has already been proven by its applications. The system allows for a user-friendly digitizing of photogrammetric data with simple and fast editing capabilities, thus representing an important link in the chain of photogrammetric stereocompilation. However, problems associated with compatibility with other systems, data transfer speed and storage capacity, optimal data entry for feature names, and further interactive graphics data processing, still have to be solved. It seems, though, that the total photogrammetric digitizing system is less complicated than generally assumed.

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