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A REVIEW OF DATA ACQUISITION SYSTEMS - PRESENT AND FUTURE
AND THEIR EFFECT ON CARTOGRAPHIC INFORMATION SYSTEMS

1. ABSTRACT

Over the last two decades there has been a gradual advancement of
digital technology within most mapping organizations, especially in the
field of computer-assisted cartography, the efficiency of which is
greatly influenced by the processes of data acquisition; the encoding
of various information for storage, and the manipulation of data within
the system. Within any system environment the data must be structured
to facilitate both information access and retrieval. For the
digitization of existing graphics, several systems are discussed.
Among them we find manual digitizing, automatic tracking (photo-sensing
devices or laser beam) and automatic raster scanning systems (drum or
flat bed scanners). Using aerial photography, data could be collected
digitally during photogrammetric stereocompilation or automatically
scanned for the production of profile data or dense digital elevation
models. The effects of data acquisition systems on the process of
encoding and structuring cartographic information systems are
discussed. Special software for the structuring of data and possible
future systems are acknowledged.

2. INTRODUCTION

For more than two decades, the rapid developments in computer
technology and computer graphics, particularly the data acquisition
hardware and software, are having a great impact on the entire field of
mapping. The objectives for data conversion from graphic
(analog)-to-digital are: increased speed, precision, versatility,
improved operational characteristics, uniform quality of output and the
conditioning of output data for further use.

At present, the process of analog-to-digital conversion is performed by
the digitization of existing graphics, direct digitization from
photogrammetric instruments during stereo-compilation or by
processing of digital data generated by automated photogrammetric
instruments (digital elevation models).

The integration of interactive multiple-station subsystems in a distributive computer network environment will provide an unprecedented opportunity for achieving optimum production levels and general cartographic data bases to fulfill the requirements for multi-mapping activities.

The development of sophisticated computer software for on-line graphic display and editing; and for data base storage, retrieval and manipulation is an integral part of the overall system design and operation.

3. DIGITIZATION OF EXISTING GRAPHICS

Digitization of graphic data prior to incorporation into a cartographic data base represents a good portion of the total work load in automated cartography. Examples of such graphic source data are existing maps, photogrammetric mapping manuscripts, orthophoto maps, etc. Graphic data is an analog record and the process of digitization is regarded as a conversion from analog-to-digital record.

The methods of digitization may be classified according to the technique and equipment used as follows:

1. Manual, by retracing the graphic features on a digitizer table with a cursor or stylus,

2. Semi-automatic, by employing a line-following device in conjuction with a human operator.

3. Automatic, by processing the entire graphic with a raster scanning digitizer.

In the first two methods, the form of the output is a series of x and y coordinates in the digitizer coordinate system; while the third method produces a digital output in a raster form.

3.1 Manual Digitization

The basic components of the system are: the digitizing surface or table, tracking device (cursor), output interface and a processor. Additional devices may be used (based on the desired system configuration), such as visual coordinate display units, alphanumeric CRT's, graphic CRT's, magnetic tape units, disk units, floppy disks and cassette recorders. Software is an integral part of the system. It varies from software for the recording of digitized and keyed information to that for the manipulation of recorded data (transformation, computations, interactive display and editing).

A number of graphic digitizers are available in varying standard sizes from 0.30 x 0.30 metre to 1.50 x 1.50 metre. Most of those digitizers have a resolution of 25 micrometres and an accuracy of $\pm$ 100 micrometres; and few of them have a resolution of 10 micrometres and an accuracy equal to or better than $\pm$ 50 micrometres.

The digitization process is simple. An operator moves a cursor progressively along a given line. A coil is attached to the cursor and generates an electro-magnetic field which is picked up by a grid of electrical conductors. This generates a series of pulses wich indicate the x an y coordinate values.

Manual digitization should be carefully evaluated by the user. In the case of complex graphics, such as topographic maps, the process is far too slow and is subject to unpredictable human errors. Human problems arise because tracing requires considerable hand and eye coordination which is difficult to maintain over extensive periods of time when curved lines are being traced.

To increase the efficiency of digitizing graphic material and to improve the accuracy of digitization, an Aided-Track cursor was developed by RCA (Hunka, 1978). The design goals of the cursor were to tolerate tracing errors of 0.8 to 1.6 mm, depending on an operator selection and to correct the error to $\pm$ 100 micrometres of true coordinate value.

The cursor incorporates a rotatable linear self-scanned photodiode array onto which the feature being digitized is imaged. The coordinate values given by the encoder of the digitizing table define the position of the centre fiducial dot of the cursor. Any feature within the aided-track circle of the cursor will generate the necessary correctional factors with respect to the encoder values. A dedicated minicomputer is used to combine the digitizing encoder output with the array correctional counts to derive the feature's coordinate values.

To maintain the accuracy of digitization in the presence of line curvature a computer is used in conjuction with the cursor to calculate a rotational signal from prior coordinate values to maintain the array perpendicular to the curve traced.

Engineering evaluation of the aided-track cursor system (Hunka, Damon-1979) indicated that, the average standard deviations of error are 40 micrometres for the aided track data versus 90 micrometres for normal trace data. Tracing speed tests indicated that an improvement of greater than 3 1 can be realized by the aided-track system.

3.2 Semi-Automatic Digitization

This method is characterized by the use of an automatic line-following device which digitizes individual graphic features under human supervision. An operator is required to position the device on each feature initially and select the appropriate branch when a line intersection is detected by the system.

Based on this technique, the "Fastrak" digitizer system was developed by Laser-Scan, Cambridge, England. A basic requirement for the system is that, the map to be digitized has to be reduced photographically on a negative film (maximum area 96 x 68 mm). The system consists of three units: the optics unit, the operator console and the computer. The optics unit contains the optical and laser equipment, the hard copy plotter, the power components and the holder of the source map film

negative. The operator console contains the display, controls and interface electronics.

The system hardware is based on interferometrically controlled laser deflection system. A red helium-neon laser is used for reading from the film negative (the digitizer function) and a blue argon ion laser for writing (the display and plotter hard copy functions).

To digitize a feature the operator positions the cursor on the feature, selects control functions (e.g. straight, curved, point symbol), keys-in code information and initiates the automatic line follower. In the reading mode, the laser probe systematically scans the feature in a local raster scan and this scan pattern changes between horizontal and vertical scanning as the feature changes direction. The processing of the scanned data is done simultaneously with the scanning process by the computer wich sends line co-ordinate information into storage and returns guidance information.

In the writing mode, the blue laser beam travels the same path as the red beam and is used for painting out digitized features by writing on a film overlayed on the film negative of the map. It is also used for producing a hard copy by writing on fiche size diazo film, or it may be deflected directly to the large screen and used as a cursor or for presenting required graphic or alphanumeric information in a refreshed display.

3.3 Automatic Digitization

Totally automatic digitizing systems use a scanning digitizer for rapidly transducing graphic data into the computer. Automatic scanners are photosensing devices which scan documents in a pre-set criss-cross pattern in a "raster" form. The scanners can also be equipped with colour-separation sensors, which permit graphical information to be digitized selectively. Some scanners use reflected light to work directly from hard copy material mounted on drums or flat beds. Others use transmitted light to transduce graphic data recorded on transparent film.

At present, several systems are available. The earliest was the IBM drum scanner/plotter developed by IBM Corporation for the U.S. Army Engineer Topographic Laboratories. Scanning illumination and detection is by a conventional tungsten-halogen lamp and photomultiplier arrangement. Plotting is performed by imaging the output of a solid-state light-emitting diode array onto red-sensitive film. The hardware permits the scanning or plotting of 60 x 75 centimetres formats using a 25, 50 or 100 micrometres pixel size.

A flat bed laser scanner digitizer is manufactured by Broomall Industries Inc., U.S.A. and permits the raster digitization of maps with formats up to 112 x 165 centimetres. The manuscript is scanned using a low power laser light source. The amount of reflectivity determines if a raster coordinate is recorded and stored in the control computer. The amount of data collected can vary depending on the collection resolution used. The reported manufacturer's resolution is 25 micrometres and the positional accuracy ± 50 micrometres. The flat-

bed scanner may be used in a complete automatic graphic digitizing system configuration, with the use of software for raster-to-vector conversion and interactive display and editing capability of the cartographic data.

Raster scanning is a fast process, but it has some problems in handling the volume and structure of the geometric information within the computer. The difficulties initially arise because the digitized raster image is generated in the form of a matrix of ones and zeroes which represent the black and white areas on the map. This format is suitable for regenerating the image on raster-display devices, but is inappropriate for cartographic data base and graph plotting purposes. Raster form is also uneconomical for computer storage and data-transfer times.

The development of software for the conversion from raster-to-vector is an important step in alleviating the problems of raster digitization. The raster-to-vector is needed for the storing of raster data in cartographic data bases.

Once vectorization has been accomplished, the data is in a form which permits efficient interaction by standard interactive graphic editing techiques. This interaction is required to delete unwanted information, to label the features and to alter inappropriately vectorized curves.

In recent years, the development of hardware for raster digitization has progressed faster than the development of an efficient software. Recent software development was reported by Clark (1980) for the processing of raster scanned contour sheets. The software operates on an associative array processor and a CDC 6400 computer. It was designed to perform raster-to-vector conversion, elevation tag association in a semi-automatic mode, and the interpolation of these tagged contours into a uniform grid of elevations.

4. DIRECT DIGITIZATION FROM PHOTOGRAMMETRIC INSTRUMENTS

The main objectives for the digitization from photogrammetric instruments during the stereo-compilation are:

a) The recording of accurate positions of features from aerial photography in contrast to digitizing existing maps where features are displaced and/or generalized for cartographic representation purposes.

b) The ability to create cartographic data bases to meet the increasing demand for digital data from various users and the automatic drafting/scribing of maps on flat-bed plotters.

c) The possibility of preparing maps at various scales.

d) The speed of transferring data to users and the ease of manipulating the data base.

e) The acceleration of map revision, and the speeding up of map making process.

To satisfy a "complete" digital stereo-compilation system, the following fundamental requirements should be considered:

a) The system should offer a map product not inferior to existing graphical methods.

b) The work in the analog plotter must not be more time-consuming, more tiring (physically or psychologically) for the operator, or more subject to blunders than usual graphical methods.

c) The system must support several photogrammetric instruments and should incur no more than small overhead in implementation and running costs in order to make it economically feasible.

d) The system should support on-line digitizing, graphic display and editing capabilities not inferior to graphic methods.

e) The system should have multiple entry facilities and be easily expandible both by the system designers and by the user.

f) It must retain the similarity and the ease of operation currently used in photogrammetric practice, so that the change-over will be as transparent as possible.

g) System hardware components should be standard.

To satisfy these requirements, the system configuration illustrated in Figure 1 was developed in the Topographical Survey Division, Surveys and Mapping Branch, Canada. The system supports several photogrammetric stereo-plotter digitizing/editing stations. Each station consists of a photogrammetric instrument, microprocessor interface terminal, and a CRT graphic display terminal. The system supports a cartographic editing station consisting of a table digitizer and a CRT graphic display terminal interfaced to a digital computer. The computer supports I/O devices (mass storage disk system and magnetic tape drive system) and a proof plot drafting machine.
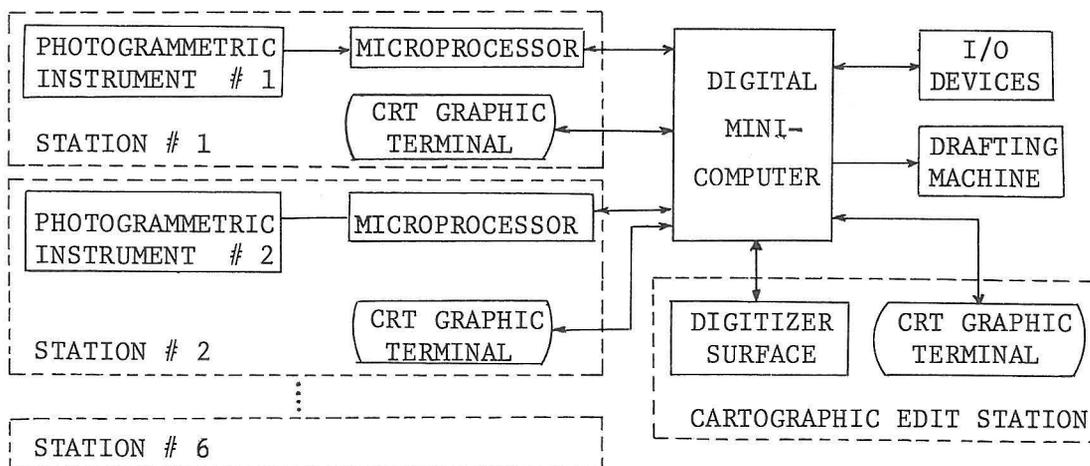

Figure 1. Multiple-Station Interactive Photogrammetric Map Compilation

4.1 Photogrammetric Instruments Attachments

For digital stereo-compilation, the measuring system of the photogrammetric plotter should be equipped with a digitizing device which picks up the co-ordinates in the form of video pulses. The present available digitizing devices operate in the following modes: incremental or absolute. In the incremental type, the positions are coordinated in terms of the total count of distance measurements traversed from an initial starting point. In the absolute type, the positions are coordinated in terms of fixed values for each axis.

Based on the principles of measurements, three types of device are commonly used with the photogrammetric instruments. These are: the linear systems, the rotary encoders systems, and the digitizing surface systems.

Due to the wide variety of analog photogrammetric instruments available, the choice of the optimum digitizing device attachment is dependent on the mechanical arrangements made for measuring the X,Y,Z coordinates in the model space of the instrument.

In instruments with handwheel control of the measuring device motion, the use of rotary shaft encoders is widely employed if the instrument is used for digital map compilation purposes. This does not rule out the possiblility of using linear incremental or linear absolute systems with this type of instrument. At the present time, the use of a high precision linear scale attachment is limited due to the costs involved.

4.2 Microprocessor Interface Terminal

This interface provides the link between the analog photogrammetric instrument and the computer. The microprocessor interface unit tracks the stereoplotter by counting up or down the X,Y and Z axes counters as a function of the amount of encoder shaft rotation which is proportional to the linear distance traversed by the stereoplotter. The X,Y and Z model coordinates read are then transformed to ground coordinates by the micro-processor, and are sent serially to the computer where the data is entered into the data base.

4.3 Graphic CRT Display Terminal

Three distinct categories for display technology are available: vector refresh displays, video (raster) displays and storage tubes.

The vector refresh displays employ a random-screen write capability and the image is refreshed each 1/25th to 1/60th of a second. The image is created from a series of strokes (vector, arcs, or points) by the display hardware in response to instructions stored in the display refresh buffer. The refresh displays have excellent brightness, small spot sizes, medium resolution, direct use of digital instructions and image dynamicism. Operationally, the vector refresh display terminals sacrifice some throughput potential and have limitations in the display

capacity and associated display area.

In the Video display type, all the digitized information must be
transmitted to the screen in a raster format independent of the logical
connection between points on a display. The conversion of data format
from lineal to raster is performed by software or a hardware device.
Operationally, with video displays, interactive graphics are difficult
without a backup of an indexed data base of lineal features retrievable
by a given coordinate system.

In the storage display type, all the information is written on a storage
CRT which does not have to be refreshed constantly. As compared with
the vector refresh display type, the storage tube displays
significantly more information which does not have to be refreshed
constantly. The weakness of storage type displays lies in the inability
to erase any displayed feature and the display of the modification
without rewriting the entire screen display.

4.4 Digital Computer

To support an on-line interactive digital map compilation and editing
system with several photogrammetric instruments (as shown in Figure 1)
a complex software system is required to perform the task. In this
circumstance, a powerful dedicated computer system with 128K-256K
16-bit words core memory becomes inevitable to support the sytems in a
time-sharing, multi-task environment (e.g. data collection, data
processing, interactive, graphic display, interactive editing, data
base management, plotting and programming).

4.5 Storage Device

In digital map compilation, depending on the type of terrain, the
density of detail to be mapped and the sampling rate, a digitized
stereo-model may contain from 10,000 to 100,000 individual points.
Considering, that each X,Y and Z coordinates uses 2 - 4 bytes (single
or double precision), then the use of a high speed, high-density
storage device is necessary.

4.6 Software

The main components of the software system for interactive
photogrammetric map compilation are:

a) Software for data collection from the photogrammetric instrument
   with appropriate cartographic code assignment; and the
   transformation of digitized X,Y, and Z coordinates from model to
   ground coordinate system.

b) Software for interactive graphic file design, display, and editing
   purposes.

The software is normally designed as several modular tasks communicating with the user on a real-time, event-driven (user request), priority structured basis.

The interactive graphic programs are usually accessible through a menu, a keyboard, or may be addressed directly by application programs. The main features of the interactive graphics software include:

a) Placement, deletion, modification, and movement of design elements, such as lines, polygons, arcs, circles, ellipses, text and curves.

b) On-line user definition of any combination of design elements as a cell to be added to a cell library; placement, manipulation and scaling of any cell.

c) Storage and retrieval of intermediate and final designs.

4.7 Operational Procedures: Interactive Display and Editing

Editing can be done during data collection, after the completion of some compilation or after the data have been plotted and reviewed. Editing and graphical display are closely related. The following are some of the combinations that can be graphically shown on the interactive display system.

- display one or more overlays in combination with the class of data as identified by association code such as roads, railroads, rivers, etc.

- display with or without: a pattern (e.g. railroad), a symbol (e.g. marsh, bulding, etc.), a line type (e.g. solid line, dash, dotted, etc.) and line weight.

Also related to editing is the measurement of data. It is possible to measure the distance between graphical elements, the angle between lines or the area bounded by a polygon. Equally important is the precision and exact location and placement of data, e.g. placing a geodetic monument exactly on the map.

The editing, like the display function, is controlled by a menu command. This includes the classical editing capabilities such as add, delete, modify, and smooth data. It is possible to add line data, text data symbols and so on. Part or all of a data element can be deleted. Two segments of data can be joined into one continuous smooth curve. It is possible to modify data such as in the case of road intersections or contour and stream intersections.

These are a few examples of the numerous editing commands which are available in the present interactive graphic editing systems.

5. INTERACTIVE MAP COMPILATION IN A DISTRIBUTIVE NETWORK

As shown in the previous section, the present trend is in the develop-

ment of multiple-station interactive map digitization. These stations may comprise photogrammetric instruments or digitizer tables for the conversion of analog-to-digital data. They are characterized by the existence of graphic CRT's for display and editing purposes and the recording of data in a cartographic data base.

The future trend will be in the development of multiple-station, multiple subsystem in a distributive computer network. The configuration of the total system and the different subsystems will be dependent on the user's requirements, the availability of the system to several users (multi-disciplinary approach), the source of digitization (aerial photography, existing maps, and charts or digitally stored information from other data banks), the structure of the common data base, inter-relation between the various subsystem components, and the form of output.

A possible configuration of such a system is illustrated in Figure 2. The total system may have more than one subsystem performing the same type of analog-to-digital data reduction (e.g. photogrammetric map compilation at various scales).

An interaction between the data base subsystem and the various input, output, digital data manipulation sub-systems will exist. Each subsystem will perform as a separate entity and may interact with other subsystems. Each subsystem will consist of several stations, interfaced to a microcomputer. Depending on the activities within a subsystem, the level of the digital processor and the local storage and I/O activity will be determined. As described before, digital data acquisition requires interactive display and editing capabilities. The level of the editing software required is determined by the activity. To minimize the load on the microcomputers serving several stations in one subsystem it is possible to perform extensive and time consuming editing function in a separate editing subsystem. In this case the functions of the cartographic data input subsystems will be limited to those required for the acquisition of digital error-free data.

The development of the distributed systems will be a natural outgrowth of requirements to increse our computational abilities far faster and more efficiently. Even though the individual components operate autonomously, the common master data base subsystem will be the unifying element. In addition to that, the various subsystem components will be coupled in such a way to provide a high level of overall system integration.

6. AUTOMATED PHOTOGRAMMETRIC MAPPING SYSTEMS

These systems are characterized by the automatic digitization of aerial imagery (scanning), and the matching of conjugate imagery (correlation). The scanning operation involves the conversion of light signals (photographic densities) into electrical (video) signals. This process may be performed by the use of: electronic scanners (CRT devices, vidicon type devices, or image dissector devices); solid-state scanners (self-scanned photodiode devices, charge-coupled devices, etc.); and electro-optical (lasers, light-emitting diodes, etc.).
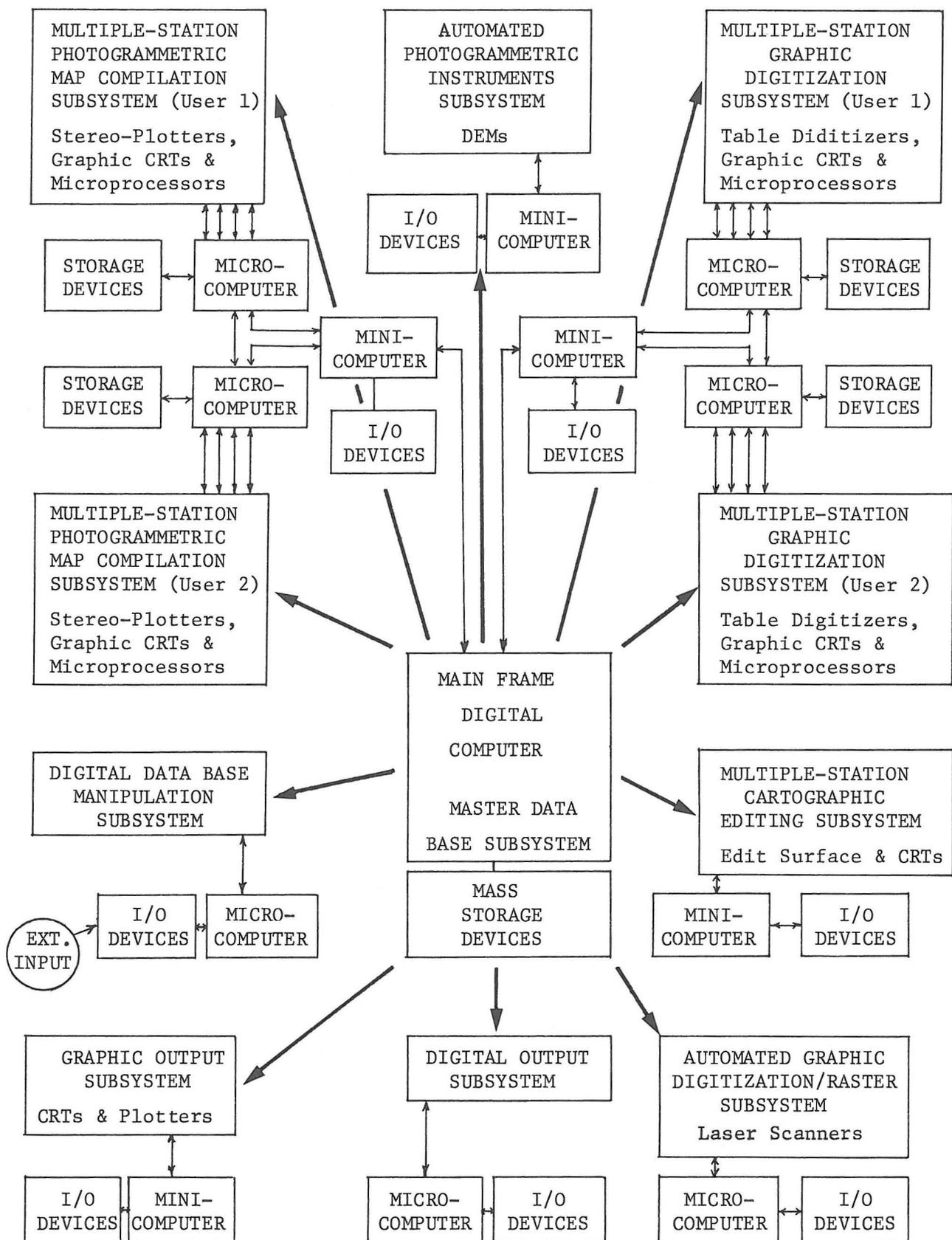
MULTIPLE-STATION
PHOTOGRAMMETRIC
MAP COMPILATION
SUBSYSTEM (User 1)

Stereo-Plotters,
Graphic CRTs &
Microprocessors

AUTOMATED
PHOTOGRAMMETRIC
INSTRUMENTS
SUBSYSTEM

DEMs

MULTIPLE-STATION
GRAPHIC
DIGITIZATION
SUBSYSTEM (User 1)

Table Diditizers,
Graphic CRTs &
Microprocessors

STORAGE
DEVICES

MICRO-
COMPUTER

I/O
DEVICES

MINI-
COMPUTER

MICRO-
COMPUTER

STORAGE
DEVICES

STORAGE
DEVICES

MICRO-
COMPUTER

MINI-
COMPUTER

I/O
DEVICES

MINI-
COMPUTER

I/O
DEVICES

MICRO-
COMPUTER

STORAGE
DEVICES

MULTIPLE-STATION
PHOTOGRAMMETRIC
MAP COMPILATION
SUBSYSTEM (User 2)

Stereo-Plotters,
Graphic CRTs &
Microprocessors

MULTIPLE-STATION
GRAPHIC
DIGITIZATION
SUBSYSTEM (User 2)

Table Digitizers,
Graphic CRTs &
Microprocessors

MAIN FRAME

DIGITAL

COMPUTER

MASTER DATA

BASE SUBSYSTEM

DIGITAL DATA BASE
MANIPULATION
SUBSYSTEM

MULTIPLE-STATION
CARTOGRAPHIC
EDITING SUBSYSTEM

Edit Surface & CRTs

EXT.
INPUT

I/O
DEVICES

MICRO-
COMPUTER

MASS
STORAGE
DEVICES

MINI-
COMPUTER

I/O
DEVICES

GRAPHIC OUTPUT
SUBSYSTEM

CRTs & Plotters

DIGITAL OUTPUT
SUBSYSTEM

AUTOMATED GRAPHIC
DIGITIZATION/RASTER
SUBSYSTEM

Laser Scanners

I/O
DEVICES

MINI-
COMPUTER

MICRO-
COMPUTER

I/O
DEVICES

MICRO-
COMPUTER

I/O
DEVICES

Figure 2. Possible Configuration of A Distributive
Digital Mapping System.

031.

The matching of the video signals is done by electronic or digital correlators (Allam, 1980).

Automatic photogrammetric instruments are used for the production of one or more of the following outputs: digital elevation models (DEM's) in a profile or a grid form, orthophoto, stereo-ortho photos (stereomates) and a hard copy contour print. Examples of instruments are the Universal Automatic Map Compilation Equipment (UNAMACE), the Gestalt Photomapper System (GPM-II), the Bendix AS-11B-X system etc.

For cartographic data base purposes, the primary interest will be in the DEM's where contour line sheets may be produced by interpolation methods (Allam, 1978). The orthophotos may be used as a source document for digitizing planimetric data on manual digitizers and the orthophoto/stereomate may be used for direct compilation as a scaled photogrammetric model.

In the future, the recorded video densities from these instruments or those generated by scanning imagery on densitometers will be used for the automatic extraction of planimetric features (pattern recognition). Feature-signature data bases are a near future possibility and they will be associated with terrain relief or DEM's data bases.

7. CARTOGRAPHIC DATA BASE SYSTEMS

From the above description of the numerous present and future data collection systems, the data is recorded in a lineal (feature) form or a raster form. Figure 3 illustrates the relation between the data base and data collection subsystems.

At present, the emphasis is on the design and generation of feature oriented cartographic data base systems. The design of the data base is dependent on the user's requirement and the operations associated with the stored data. For example, to be able to construct a map graphic, the following five different information types must be available:

a) Position (coordinate data) - which defines the location of feature relative to a reference coordinate system.

b) Feature Definition (code) - which identifies the type of feature.

c) Feature Attributes - which is the information used to characterize the feature in terms of its apparent properties. For example for a "contour" feature, its attributes may be: height (numeric), where (Land, icefield, glacier, etc.), and type (normal, depression, auxiliary, etc.).

d) Graphic Definitions - constituting both an exact definition of how a feature is to appear and the procedure affecting the depiction.

e) Land Mass Topology - which defines the features in relation to each other. This information is needed to recognize and use the position data of neighbouring features both for the generation of feature
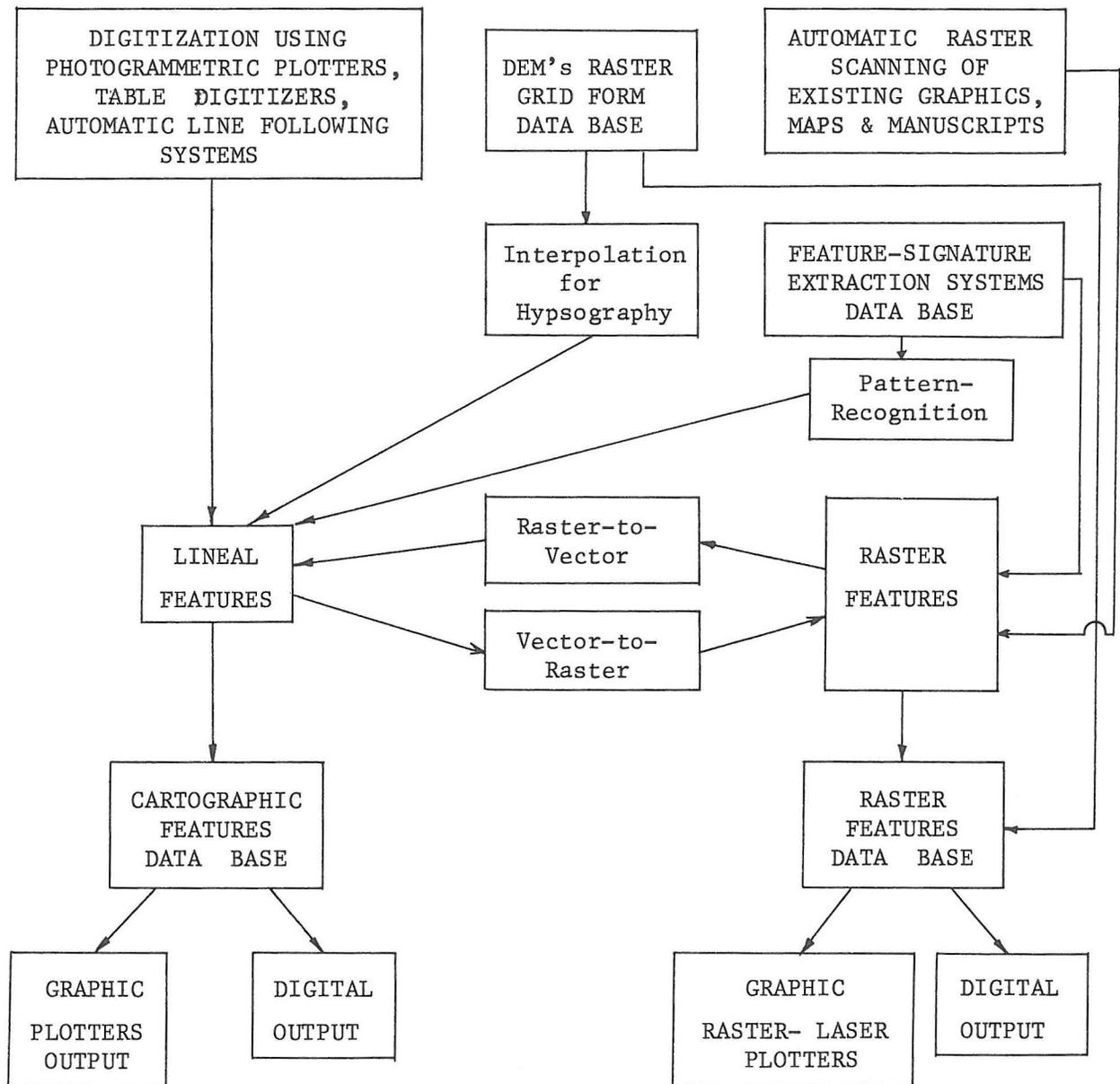
Figure 3. Inter-relation between Cartographic and Raster Data Bases

display (depiction) as well as in the deployment of symbology.

The data collection procedure has a bearing on the structure of the data base. For example, features may be collected into overlays (hypsography, roads, hydrography, etc.).

A complex data base structure may be used if the system consists of several data collection subsystems, serves several users and has a variety of output facilities. Even though, the present trend is directed towards the generation of lineal feature cartographic data bases, raster form data structures will be used more in the future. The development of high-quality laser printers and laser plate-makers will definitely open new vistas for the use of raster cartographic data bases. The future development of software for the reduction of raster graphic data volumes, or the generation of new mass storage devices will make the process of maintaining and manipulating raster data bases feasible.

The future success of digital data collection systems is dependent upon the data base system used. Standards for digital data collection, classification and accuracy will play an important role in the process of data transfer between various users and will ensure a maximum interaction between various disciplines.

8. CONCLUSIONS

The current techniques for the digitization from existing graphics or directly from a photogrammetric plotter during stereo compilation will continue. Improvements in hardware and software will improve the operational procedures by increasing the speed of data communication, digitization and editing. Systems with interactive editing capabilities will dominate and the development of systems will be based on multiple-subsystem approach using distributive computer network.

Raster scanning hardware and software for raster-to-vector conversion will be used extensively in the future. The development of automatic feature identification will open new dimensions for the use of raster structure data bases.

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