John V. Sharp
IBM Data Systems Division
Kingston, New York

*Data Processing Using Photogrammetric Instrumentation**

Digital data processing equipment can perform many of the functions of classical photogrammetric and related map-production equipment.

(*Abstract on page 147*)

SUMMARY

The uses of standard and special experimental equipment include digital techniques related to the following areas:

Instrumentation for camera, ground control, and navigation which produces film and data required in the conversion to digitized input records for experimental map production systems.

Equipment to process these digital records for control extension; for rectification of tilt, scale and other system distortions; and for computation of elevations, removal of relief distortion, and production of contour and other mapping data. With this processed data, contour maps, orthophotos, relief maps and charts can be experimentally produced. In addition, profile and volumetric data can be supplied to compute engineering construction designs and models.

Experimental digitizing equipment which can convert this acquired data to digital form. (Simple line drawing scanners to more complex film scanners for digitizing lines, type characters, printed data, line drawings, photographs, and diapositives are described.)

The purpose of this paper is to discuss the experimental capabilities of digital processing and associated experimental equipment which can perform these mapping functions in a predominately digital system. Certain cartographic equipment functions can also be performed experimentally by special equipment. A Commission II proposal, based on this paper,* is contained in its appendix for presentation at the Tenth International Congress on Photogrammetry.

Introduction

A general report and several invited papers were presented under Commission II (plotting, theory and instrumentation) at the Tenth Congress of the International Society of Photogrammetry at Lisbon, Portugal, September 7–19, 1964. These papers summarized new developments in areas as automatic instruments[1], analytical instruments[2], and classical analog instruments (by Prof. W. Schermerhorn). In a paper on "Fundamental Problems," Prof. B. Hallert discussed the

* The material in this paper has been cleared for open publication by Department of Defense. Review of this material does not imply Department of Defense endorsement of factual accuracy or opinion.

[1] Esten, Randall D., "Automatic Photogrammetric Instruments," Photogrammetric Engineering, vol. XXX, No. 4, p. 544, July 1964.

[2] Schmid, Dr. Hellmut H., "Analytical Photogrammetric Instruments," Photogrammetric Engineering, vol. XXX, No. 4, p. 559, July 1964.

* Presented as an invited paper at the Tenth Congress of the International Society of Photogrammetry at Lisbon, Portugal, September 7–19, 1964.

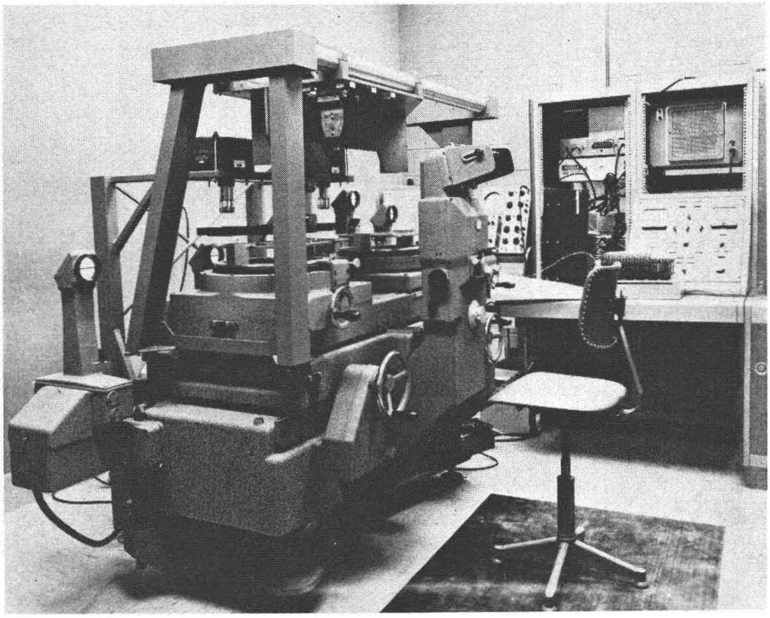


FIG. 1. IBM Photo-digitizing Stereocomparator (*Text on page 146*).

measurement and analysis of errors which affect instrument operations and the quality of the resulting maps, orthophotos, and related data.

A factor of growing significance in these areas is the present and potential uses of digital data processing techniques and equipment. Since the previous I.S.P. Congress in 1960, the use of digital techniques in automatic instruments has been increasing at a rapid rate.

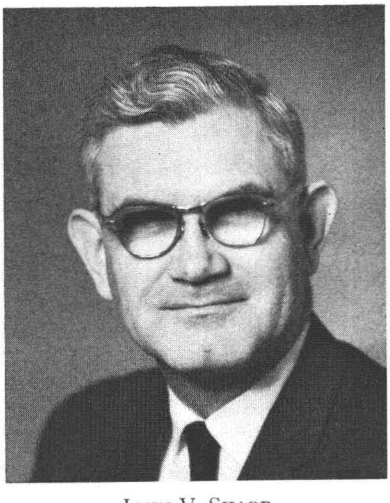
Analytical Instrument Systems, using mono- or stereo-comparators are measuring control data for processing in computers as large as the IBM 7030 (STRETCH) system, a major change from the desk calculator techniques available to such pioneers as the late Dr. Earl Church of Syracuse University.

Classical Analog Plotting instruments are now generally equipped with digital-data output recorders. This recorded data is used in digital numerical analyses, bridging adjustments, and engineering design problems which make extensive use of data processing.

The fourth paper of Commission II was devoted to the "Fundamental Problems" of instrument accuracy and quality. Errors in film and instruments have, for many years, been measured, recorded, and converted into digital data for analysis by computers for error calibration.

This paper proposes to emphasize the major areas in a mapping system using photogrammetric instrumentation, where increased uses of digital techniques are potentially applicable. Some of the areas of potential application are based on development work at IBM, Kingston, New York. Three principal areas amenable to digital techniques are:

1. Digital data acquisition from ground surveys, flight missions, and instrument calibration measurements.
2. The forming of map and orthophoto compilation manuscripts from stereo diapositives.
3. The production, editing, and annotation of map or chart manuscripts and masters.



JOHN V. SHARP

Data Acquisition Operations

Production of a new map begins with the search of a document file containing known ground control and identification data, cadastral data, and previous contour maps, etc., which may be available. These data have usually been manually recorded for flight and ground-control survey planning. In addition, film, camera, and diapositive printer calibration, as well as lens distortions, camera-platen flatness, atmospheric refraction data, and all other measured system distortions are usually on file for use. Much of these data can be converted and stored in digital form. At present, much of these calibration data are made available in various non-standard forms from manufacturing and testing organizations. Considerable digital data output from measuring equipment is hand written and then key-punched. Much of the measuring equipment could conceivably be automated to produce digital data directly. This change could be used to increase the accuracy of this data by eliminating manual reading and keying errors, when such improved mapping quality is justified.

Flight Film and Data Acquisition

Acquisition of accurate aerial images remains a photographic camera process. A digital recording substitute for this process appears remote. In addition to film acquisition, the digital recording of camera flight station data is needed. The approximate location, and attitude, if obtained in digital form, would reduce accidental errors which occur in transferring this data to the computer for use with an analytical resection and orientation program.

Field Data Acquisition

In field-data acquisition, instruments such as theodolites, transits, distance-measuring equipment, barometric devices, tapes and timers are used. These instruments are usually manually read and recorded. Each of these data-recording operations are potentially mechanizable; but again, key-punching of handwritten field data with its potential recording errors is the digital conversion technique primarily used because of its low cost.

Errors Inherent in Manual Data Acquisition

Thus, most data acquisition operations are now, primarily, a manual data-recording operation. Keying error rates of 1/500 to 1/1000 are not uncommon in key-punch and verification operations. These accidental errors are a source of major concern. Analytical control extension and adjustment can minimize but not remove the effects of such accidental errors in the source data acquired. Only if data is automatically recorded and converted to digital form will such errors be reduced.

Photogrammetric Data Processing

I would next like to discuss the progress that has been made in the development of a Digital Automatic Map Compilation System, using this acquired data, to convert aerial diapositives to contour and orthophoto manuscripts. This development work, at Kingston, New York, has been largely supported by U. S. Army (GIMRADA) and IBM research funds; other agencies have assisted in collateral application areas.

The DAMC system (Figures 1, 2; Figure 1 is on the title page) is now digitizing and processing digital photographic input data of varying quality up to a resolution of 400 scan lines per inch. A potential of 1,000 lines per inch exists, but is not yet being used. Approximately 40 square inches of each stereophoto area are simultaneously scanned, converted point by point to density-level digits, and recorded on magnetic tapes. All survey data

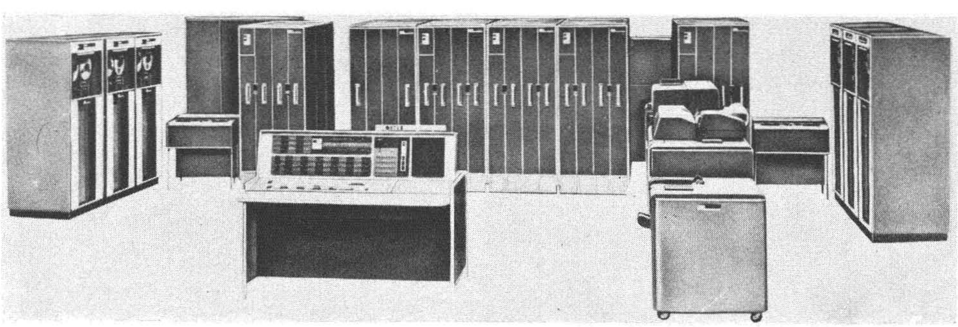


FIG. 2. Data Processing System (7094).

associated with aerial stereo photographs must also be digitized, including precise control data, obtained from ground-control and control measurements on the IBM digitizing stereocomparator (Figure. 1) and camera and other distortion measurements. The details of the System's operation were described in a contributed paper, "Automatic Map Compilation Using Digital Techniques," as part of a paper on Automatic Mapping Instruments.

The control data measurements made at this same time are also usable for aerotriangulation, including strip and block adjustment. These digital techniques are well established and require little comment. The latest progress in these techniques was reported by Dr. Schmid in his paper cited above.

The photo (Figure 3) and control data are processed in the IBM 7094 system (Figure 2). The following computer operations are being performed from this input digitized data:

- Resection and orientation from stereo photographic control data measurements.
- Rectification of photographic data.
- Scaling of photographic data to printout scale.
- Correction of photographs for all measured distortions in X and Y.
- Orthographic correction of photographs.
- Production of contours of various widths.
- Preparation of profiles for a digital terrain model for engineering design applications.

Printing map compilation manuscripts for editing is performed by the computer from output data stored on magnetic tape. A precise CRT printer is provided by the digitizing stereo-comparator operating in essentially a reverse mode. This instrument converts this data into one of several photographic forms, as desired by the user. Present outputs generated from this digital mapping system are printed onto film or diapositives; those which have proven feasible are:

- Rectified and scaled photographs
- Ortho-corrected photographs (Figure 4)
- Ortho-photographic maps with contours
- Contour maps (Figures 5 compared with 6A and 6B)
- A grid (for printer calibration or map overlay; Figure 7)
- A checkerboard pattern (to show range of tonal printing)
- A density wedge (to show range of shaded relief)
- Digital, terrain-elevation data printed in a typed format.

Although these operations are essentially automated, human skill is required for stereoscopic identification of photographic detail, and for precise stereo measurement of control points. In addition, the final editing of maps on photoscribing materials to conform to cartographic practice requires the skill of experts.

The results of Systems I and II (as of June 1964) can be summarized as shown in Table 1.

The present accuracy of these output maps

ABSTRACT: *Digital data processing equipment can perform many of the functions of classical photogrammetric and related map-producing equipment. The recent GIMRADA-IBM automatic map compilation system digitizes and processes photographs. The system incorporates control data and is capable of accomplishing the usual photogrammetric functions including stereoscopy, orientation, triangulation, rectification, scaling, contouring, orthographic printing, profiling, lettering, etc. The digitized input information is stored on magnetic tape, and the resultant data after processing are also stored on a similar output tape which can be returned to graphic form by means of a special printer. The system constitutes one possible method for automating the complete photogrammetric procedure.*

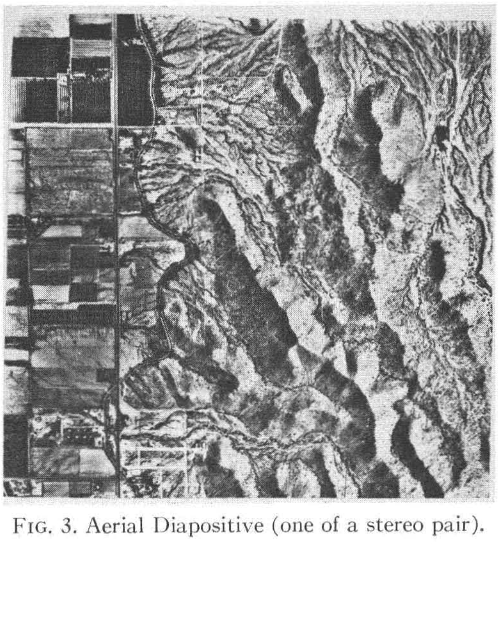


FIG. 3. Aerial Diapositive (one of a stereo pair).

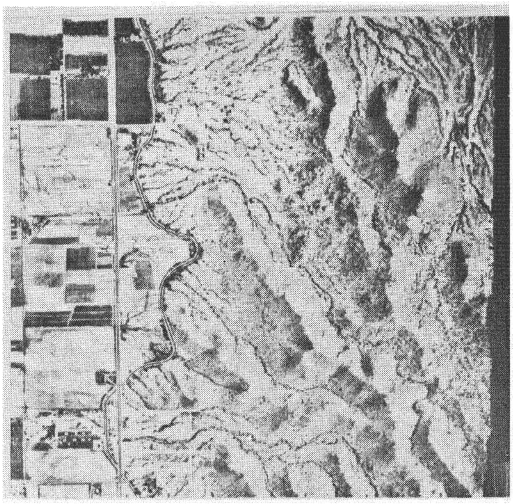


FIG. 4. Ortho-corrected Photograph.

and orthophotos is limited by several equipment and programming factors. The errors in survey and calibration data will in time limit the accuracy of the System's output. This fact suggests that calibration data for lenses, camera platens, and diapositive surfaces will be needed from testing laboratories on a point-by-point basis in the foreseeable future. This major problem is the basis for a Commission II Proposal contained in Appendix A.

PROCESSING DATA FOR CARTOGRAPHIC OPERATIONS

A special IBM drum scanner/printer was built at Kingston for experimental work on digital cartographic operations. This unit (Figure 8) scans and digitizes a chart, photograph, or drawn overlay at a maximum spot density of 1,000,000 spots per square inch over an area up to 9×20 inches. The drum scanner/printer digitizes each spot at up to 16 shades of gray and records them on an IBM 727 tape unit at a 15 KC rate. Up to 540 million bits (each spot is usually 3 bits, to permit 8 shades of gray) can be extracted from the maximum area of 180 square inches.

The data can be processed to perform some cartographic operations and to print the results on film. Examples of these operations are:

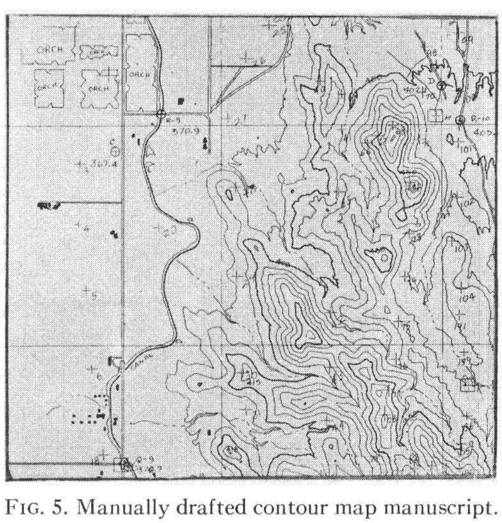


FIG. 5. Manually drafted contour map manuscript.

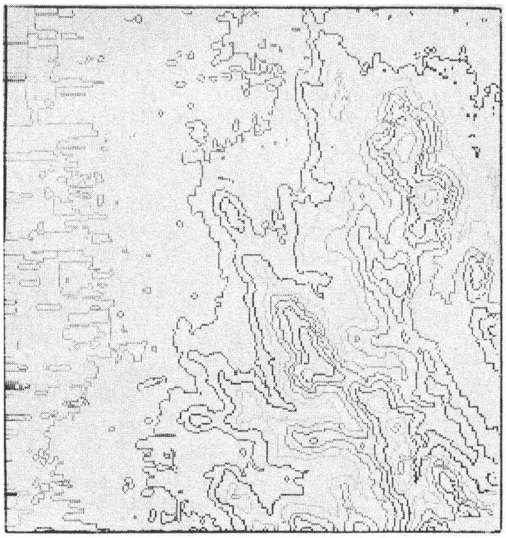


FIG. 6A. Contour map produced automatically by the *sequential* system.

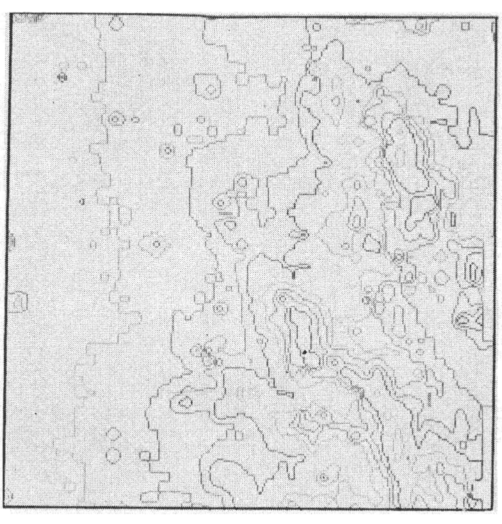


FIG. 6B. Contour map produced automatically by the *predictive* system.

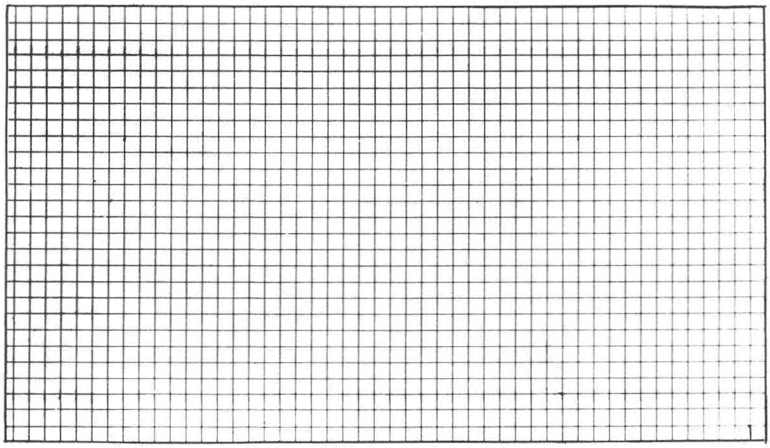


FIG. 7. A Grid.

- Changing chart, map scale, or projection
- Removing distortions
- Extracting symbols or lines from toned background (for an example, see Fig. 9), and intensifying symbols and lines (see Figure 10a)
- Adding shaded relief or tones to a map or chart (see Figure 10b)

Some examples of experimental outputs that have been obtained with this equipment are:

- A reduced chart section (Figure 11, bottom) from a chart section (Figure 11, center)
- A set of symbols extracted from the chart background (Figure 9)
- A computer-generated grid and density wedge printout (Figure 10b).
- A printout of scanned block lettering (Figure 10a).

Line tracings on translucent mylar overlay have also been scanned experimentally by this equipment. These overlays were traced in ink from a 9-by-9-inch map manuscript. Cadastral, cultural, other line data and photographic interpretation symbols can be drawn and logically identified by adjacent vertical lines which are seen by the System as a binary code. These marks can be digitized and stored for identification like the symbols in Figure 9.

Additional programming of several consolidated cartographic operations is required before effective use of this new digital technique can be made. However, we envisage an early capability to do some of the cartographic operations being performed today by manual means based on this experimental work.

With most forms of mapping or cartographic line data stored in digital form, the specified output form for various types of line overlays can be printed. For fastest output, but good line quality, symbol line data can also be converted to card form as a vector $(x+\Delta x,\ y+\Delta y)$, and plotted on a standard digital graphic plotting system (Figure 12). Line and symbol positioning accuracies approach 0.01 inch standard error (Figure 13 is

TABLE 1

	Contour Factor		*Time to Produce Model on IBM 7094*	
	A.S.P. Stds.	*I.S.P. Stds.*	*Contour Map Data*	*Orthophoto Data and Contour Map*
System I	>250	>400	*	137
System II	>180	>250	45 min.	59 min.

* System I produces the contour map and orthophoto data concurrently (if either is produced separately the time is the same). System II produces the contour map first, and then the orthophoto. Complete system diagrams are shown in "Automatic Map Compilation Using Digital Techniques," referred to previously.

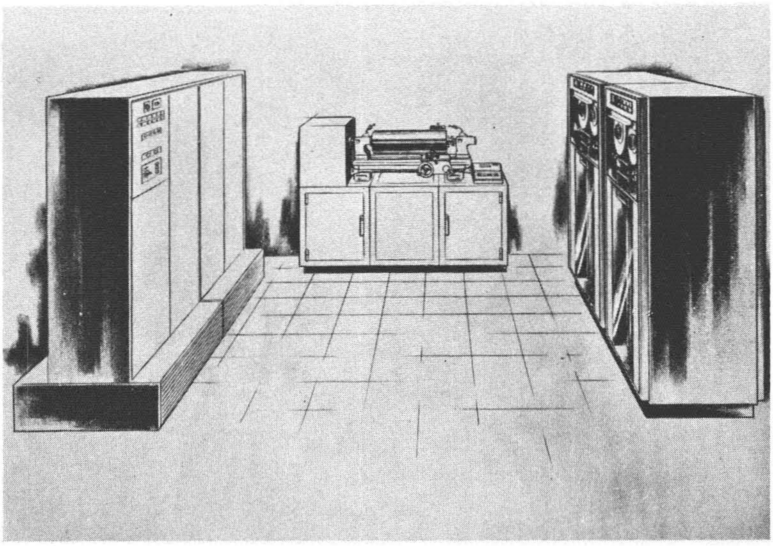


FIG. 8. Special Digital Drum Scanner/Printer.

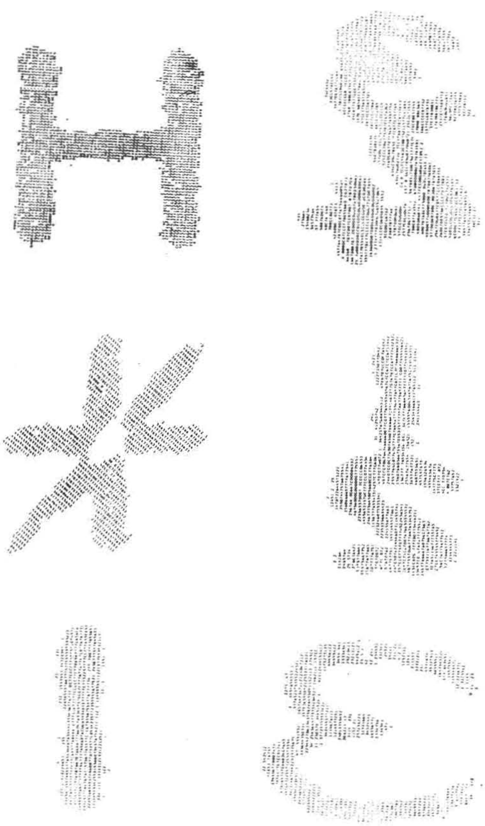


FIG. 9. Set of symbols extracted from a chart.

an example of the results that can be obtained).

The experimental IBM drum scanner/printer can print lines and stored symbols in a matrix of spots, in black, white, or shades of gray (i.e. tints), or as "screened" photographic copy at a position and spot size precision better than 2 mils. It is possible to produce, through appropriate color filters, color overlays directly onto color-sensitive film. Economical implementation of such digital techniques in mapping and charting operations will take careful planning and major programming efforts. The present experimental drum scanner scans or prints at a rate of one revolution per second. This speed needs to be increased by a factor of about 10, which would allow a 9-by-18-inch photograph to be scanned or printed in 30 minutes. When printing out one mil lines, this print-out can then be photographically enlarged six times to a useful size of up to 54 by 108-inches, with 6 mil lines. This is acceptable line quality for many charting applications.

In any digital process, the final printout of a map or chart separation negative will probably still need some field or office editing and field checking. In addition, for maximum lithographic-quality map or chart production, the "print transparencies" from the drum printer can be enlarged onto photosensitized material, such as K & E photosensitive "scribcoat," where any desired additional editing and line scribing can then be performed.

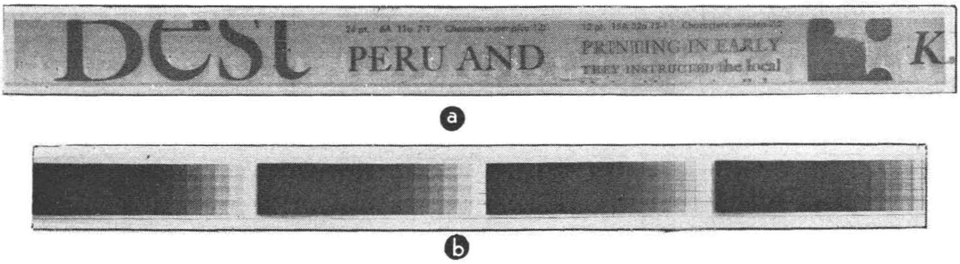


FIG. 10. Grid and printed page section print-outs.

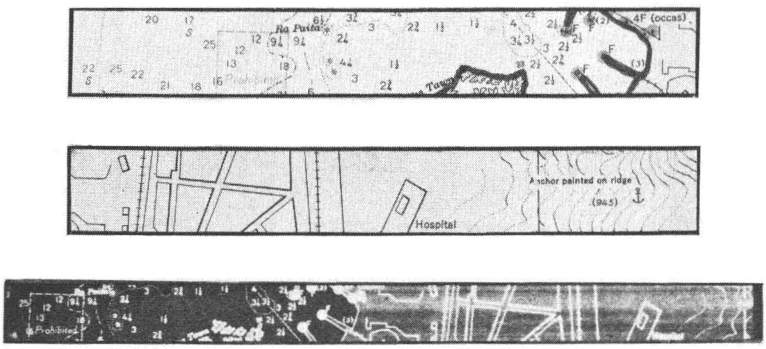


FIG. 11. Published Chart Sections. Top—strip from Nautical Chart 1265; Center—section before digital scanning; Bottom—drum printout of scanned tape (negative).

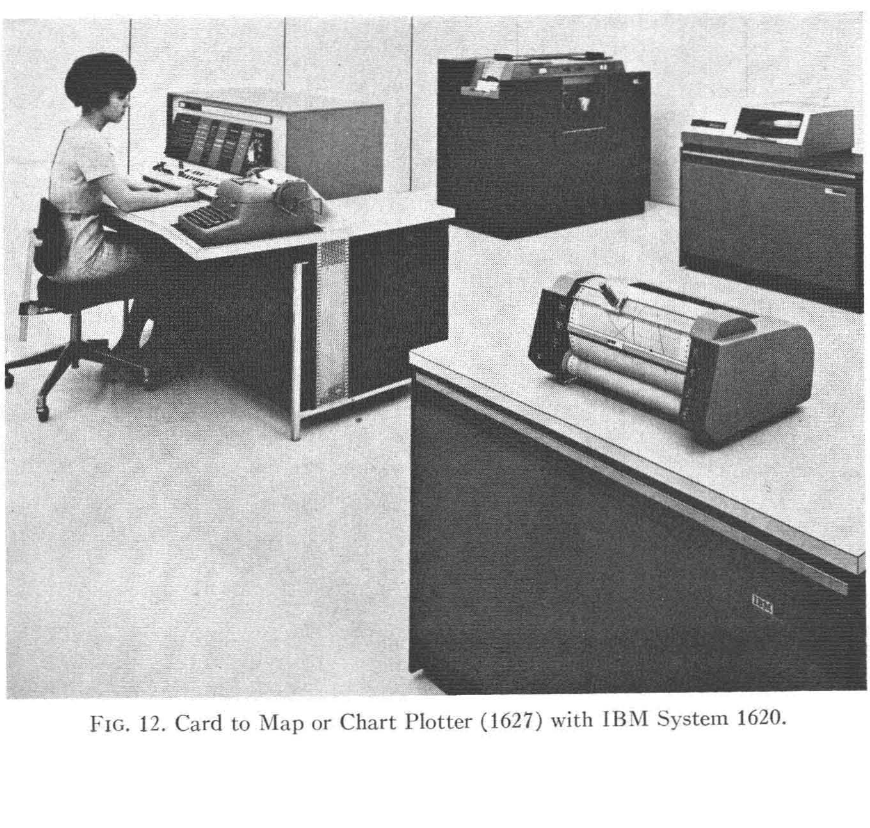


FIG. 12. Card to Map or Chart Plotter (1627) with IBM System 1620.

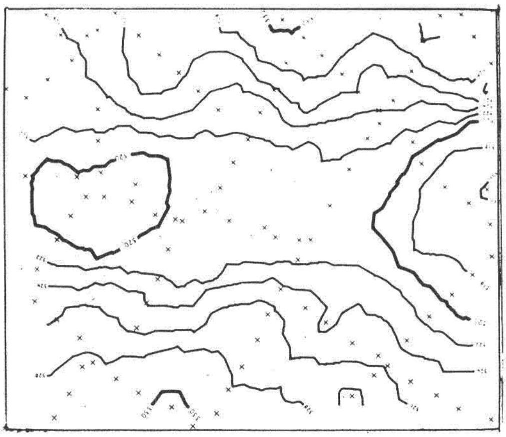


FIG. 13. Plotted Contours, Points and Characters (on 1627). Contour interval—2 units; measured elevations identified by crosses.

Although some manual operation work will always be required, a prodigious amount of hand work at many stages of the mapping and cartographic processes appears to be replaceable, in time, by digital techniques. The economic feasibility of digital techniques needs to be proven by system planning and development groups in map and chart-producing organizations under operating conditions.

These are some of the results of equipment experimentation and computer-program development at IBM to expand the use of digital photogrammetric techniques. With additional development, technically feasible mapping and charting systems can make increased use of digital techniques on photogrammetric instrumentation.

Before concluding, I would like to mention that many conventional business data processing applications are usable by mapping organizations, such as accounting, production control, storage, and data transmission. These use well-known digital techniques with presently available equipment. The equipment discussed in this paper was specially built for experimental purposes under special contracts.

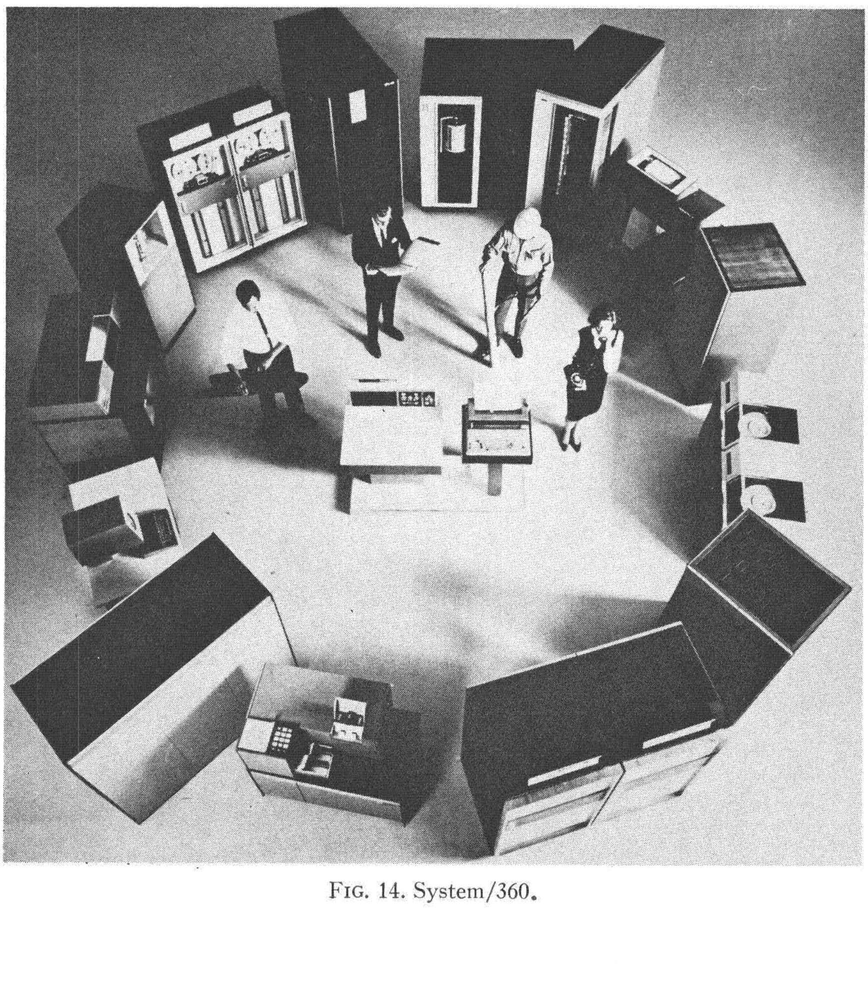


FIG. 14. System/360.

System/360

To unify many types of systems, IBM has recently announced its System/360 (Figure 14), a series of compatible data processing systems designed to reduce problem-solving time and cost, particularly when fast operating times and large core storage are needed. A wide range of System sizes and input/output devices allow a user to select the one best suited to his volume and cost needs. With this System, a mapping or charting production organization will be able to perform many of its charting and mapping operations, both administrative and technical, by digital techniques.

I hope that the discussion in this paper will help to encourage those in forward-looking mapping and charting organizations, and their related instrument manufacturers, toward developing instrumentation systems which use these newer digital techniques.

I want to thank Mr. Nowicki, President of Commission II for the privilege of presenting this paper. The information described herein includes contributions from many individuals and organizations associated with IBM.

Appendix A

Proposed Resolution for Commission II

It is proposed that manufacturing and testing laboratories be urged to supply more effectively their instrumental distortion and calibration data in a digital form for efficient and compatible entry and use in digital data processing programs and equipments. To do this, it is recommended that a committee be formed to draw suitable specifications as to the most efficient type(s) and form(s) and format(s) that this digital data and documents may take (i.e. punch cards, punched tape, magnetic tape, etc.). This calibration data should include geometric data such as lens distortions, camera platen errors, film and diapositive errors, and other known and measured instrumental errors which can affect the accuracy of photogrammetric mapping and orthocorrection of photographs. These specifications must be sufficiently broad in scope to encompass the operation of all types of automatic instruments, analytical instruments, classical (analog) instruments, and distortion-measuring equipments used in photogrammetric mapping Systems.

ERRATA

1964 Yearbook, *page 425, right column*

The Forest Service, Department of Agriculture, is reported here as not being concerned with precision mapping and as having no experience along the line of production-type mapping. The statements are accurate with respect to Forest Service research programs, but do not reflect the extensive work of the Division of Engineering in the mapping of the National Forest and its cooperation with the U. S. Geological Survey in the national topographic mapping program. The Forest Service annually invests more than $2\frac{1}{2}$ million dollars in mapping with over $210,000 of this directly in national accuracy topographic maps. This agency has contributed about 290 $7\frac{1}{2}$-minute quadrangles to the national mapping program over the past 16 years. It has perhaps three-quarters of a million dollars invested in precision first- and second-order plotting equipment.

Other agencies in the Department of Agriculture are also engaged in mapping programs, and some, such as the Soil Conservation Service, have contributed considerably to the technological development of photogrammetry. The Forest Service takes considerable pride in the role that its engineers have played in developing photogrammetry as one of the principal tools in modern map making.