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Recent Analytical Stereoplotter Developments

An electronic orthophoto printer attachment for the AS-11B-1 produces an orthophotograph and a hypsocline contour map.

ABSTRACT: *Various recent developments in analytical stereoplotters have been incorporated in the Bendix-OMI AS-11B-1 automatic analytical stereoplotter. The AS-11B-1 uses a new, powerful, microcircuit computer which enables improved orientation procedures, faster automatic operation, and increased versatility. In other analytical stereoplotter developments, improvements have been made in automation. These improvements are in the electronic scanning and correlation equipment, and in the computer programs. For experimental work, electronic circuitry for measurement of image characteristics has been added to an AS-11B automatic analytical stereoplotter. Related to the analytical stereoplotter work is the development of a computer-controlled correction system for an analog stereoplotter, and commencement of development of a computer-controlled off-line optical orthoprinter. Apparent in all of these developments is the trend towards increased versatility, simplification of model orientations, faster automatic plotting with better quality, and the application of analytical stereoplotter techniques to other photogrammetric instruments. This work has been sponsored by the Air Force Systems Command, Rome Air Development Center.*

INTRODUCTION

ARNOLD LANKTON described in 1966 the analytical stereoplotter from its introduction by Mr. U. V. Helava in 1957 through the development of the AS-11B/C automated analytical stereoplotter in 1966.[45] This paper describes developments which have occurred in the past five years. They have been directed toward increasing instrument versatility, simplifying model orientation, improving automatic plotting speed and quality, and applying analytical plotter techniques to other photogrammetric instruments. As a result of this work, many improvements have been incorporated in the AS-11B-1 automated analytical stereoplotter, which is given special attention below. The bibliography lists a number of papers which discuss particular developments in more detail.

AS-11B-1 DEVELOPMENTS

Initial tests and evaluation of the AS-11B-1 automated analytical stereoplotter indicated a substantial increase in system performance over the original experimental AS-11B system and subsequent AS-11B automation modules. The improvement resulted from changes to the viewer, replacing the computer with a new integrated-circuit model, and a complete new set of computer programs. These developments are described in the following paragraphs.

OPTICAL-MECHANICAL EQUIPMENT

The viewer used in the AS-11B-1 is basically similar to those used in earlier stereoplotters, but incorporates several improvements. The most notable change is the ex-

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tension of the format size up to 9×18 inches (twice the previous format size). In conjunction with the redesign required by this change, the cathode-ray tubes were moved from a side-vertical to rear-horizontal position. This change improves the mechanical rigidity of the optical parts of the scanner system.

The optical system was redesigned, providing significant improvement in performance of both the scanner optics and the viewing system. The optical aperture of the scanner prime lens was increased from $f/4$ to $f/2.8$, improving its resolution and light transmission. Each viewing path is equipped with a zoom system that covers a 1 to 4.5 range, giving magnifications from 7 to $31.5\times$.

ELECTRONIC EQUIPMENT

A new computer was developed for the AS-11B-1 system. The 18-bit parallel digital computer can be provided with memory capacity of 8, 16, or 32 thousand words. Operation times for add, subtract, multiply, and divide instructions, including memory access times, are shown in Table 1. Two programs have been prepared for the computer to aid in program preparation: (1) a two-pass macroassembler, and (2) an on-line program checkout routine.

The AS-11B-1 uses *dc*-type servo control systems rather than *ac* as used in the AS-11B systems. This change was made to improve the system dynamic response and because the components of the *dc* servo systems are smaller and generate less heat. Use of *dc* servo systems for the carriage simplifies accurate deflection of the scanner CRT scan patterns to compensate for servo error. Improvement of the servo dynamic response reduces the servo error to be compensated for and thus permits more accurate compensation. Deflecting the scan patterns removes servo errors from the automated system control loop; this permits the use of higher gains and larger bandwidths and enables higher plotting speeds to be achieved.

TABLE 1. OPERATING TIMES OF NEW COMPUTER FOR THE AS-11B-1 SYSTEM

Operation Type	*Add or Subtract (Micro-seconds)*	*Multiply (Micro-seconds)*	*Divide (Micro-seconds)*
Single Precision	1.3	4–5	4–5
Double Precision	1.9	27–40	65–68
Floating-Point	*17	*54	*80–100

* Subroutine.

The AS-11B-1 operator's control panels incorporate features which improve the man–machine interface compared to the AS-11B system. These features include decimal keyboard entry of numbers, an alphanumerical display for quantity names, and a control panel at the coordinatograph. Typewriter input-output facilities have been added to provide direct hard copy form of system data, from point coordinates to photograph orientation information.

The AS-11B-1 correlator was packaged differently than the AS-11B correlator and placed in the computer cabinet. The electronic circuitry was mounted on larger printed circuit boards which increased the packaging density, allowing the correlator to be built into one compact unit.

COMPUTER PROGRAM FEATURES

New programs developed for the AS-11B-1 system provide a number of additional and improved capabilities compared to the AS-11B programs, including the following:

- Improvement of exterior orientation programs.
- Provision of programs for editing gaps in automatically plotting contours and profiles.
- Increased accuracy of the mathematical projection computations.
- Increased speed in performing many system functions.
- Ability to handle increased ranges for focal length and other photograph parameters.
- Improvement of programs for sensing incompatible situations and for alerting the operator on poor correlation.

Some of these improvements are direct results of the new computer design while others result from program organization changes permitted by the computer design.

The orientation programs provide complete exterior orientation after one tour of the stereo model. During this tour of the model by the operator, the program records the coordinates of conjugate photo points and the user-entered control coordinates for 5 to 12 points. Control data is accepted in any rectangular ground coordinate system. Computation of the best set of orientation elements is performed about 20 times faster than in the AS-11B system. Upon completion of the computation, the *rms* value of the vector residuals in photo-coordinates is displayed. Individual point residuals are also available and may be displayed at the operator's command for checking purposes if the *rms* error is exceptionally large.

The AS-11B-1 computer program that computes photograph positions corresponding to a given model position does this with increased accuracy compared to the AS-11B system. The computation error is reduced from about 5 micrometers *rms* at the photographs to about 2 micrometers *rms*. The computer input and output units are reduced from 2.5 and 5 micrometers to 1.

The computer programs perform many functions with increased speed, or at higher rates, compared to earlier models. For example, the effective computation rate in computing photocoordinate changes is increased from 100 per second to 200 per second, and automatic plotting control functions such as boundary detection are performed about 15 times per second instead of about 5 times per second.

ORTHOPHOTO AND MAGNETIC TAPE ATTACHMENTS

An electronic orthophoto printer attachment developed for the AS-11B-1 system produces two types of output product: (1) an orthophotograph, which is a transformation of the input photograph image detail into an $X-Y$ map-coordinate system, and (2) a *hypsocline* contour chart, which shows contours of varying width according to the local terrain slope, thus providing both elevation and terrain slope information. Both outputs are printed on photographic film as the stereomodel is scanned in a profiling mode by the automated stereoplotter. The orthophoto is compiled by an electronic image transfer system which operates from video signals generated in the image-correlation system. The hypsocline chart is derived from elevation and terrain slope values within the computer. The design of the AS-11B-1 printer attachment was based on the electronic orthophoto attachment constructed for the AS-11B/C experimental automated stereoplotter system. The major improvements in the AS-11B-1 orthophoto printer attachment include: (1) higher orthophoto resolution, (2) easier set-up and operation, (3) increase in format size to 9×18 inches, (4) improved film-handling mechanisms, and (5) better control programs.

A magnetic tape recorder attachment provides recording of digital data and indirect communication with other standard magnetic-tape-equipped computers. The interface between the AS-11B-1 computer and magnetic tape recorder allows rapid transfer of data. In conjunction with the addition of the magnetic tape recorder attachment, modifications were made to the standard AS-11B-1 computer programs to provide recording of position data at specified intervals during profiling or contouring.

OTHER ANALYTICAL STEREOPLOTTER DEVELOPMENTS

The AS-11B-1 developments in many cases were preceded by studies or experimental developments on other systems. In one of these developments, automation modules were designed to convert manual AS-11A stereoplotters to automated systems. The conversion involved expanding the AS-11A computer by increasing its speed and memory capacity, incorporating electronic scanning and correlation equipment, and preparing expanded computer programs.

Operating experience gained on these converted automatic systems revealed areas where improvements could be made. As a result, modified computer programs were developed which increased overall system speed and accuracy. The most significant changes were in the programs that control system operation if the correlation information is low and in the programs that fill in the gaps in the plotted lines.

To further define the system growth potential and to establish accuracy and performance boundaries of the automated analytical stereoplotter, a detailed mathematical model of the AS-11B system was developed. This effort included preparation of general-purpose digital computer programs which permit simulation of system operation. The programs permit off-line determination of system accuracies as a function of input photographic quality, and also evaluation of system performance as a function of internal system parameters.

An investigation was made of advanced correlation techniques to improve automatic image registration and correlation sensitivity in the AS-11B system. Mathematical analysis showed that second- and third-order scan shaping could improve correlation quality. To verify the mathematical analysis, an experimental second-order scan-shaping system was developed and tested. The experimental work showed that the techniques could be used to advantage. The experimental work also suggested other areas whereby overall correlation performance could be further improved.

Currently, Bendix is developing advancde correlation techniques for the AS-11B-1 stereoplotter. In this program, modifications have been made to the AS-11B-1 corelation system and the system performance of the modified system is being evaluated.

Experimental measurement circuitry was developed for use in investigations of automatic planimetry classification and pass-point quality determinations. The experimental measurement circuitry measures image detail characteristics such as amplitude and spatial statistical distribution of image density. A magnetic tape recorder and the experimental measurement circuitry were integrated with one of the AS-11B systems. Experimentation in automatic pass-point selection is continuing on this instrument.

An analytical stereoplotter employing analog computing techniques was developed for operations which require less accuracy. This instrumeut, called the Chart Analysis Device (CAD), is simpler and more compact than analytical stereoplotters controlled by digital computers. This instrument was automated by incorporating electronic image correlation equipment. The automated system provides automatic profiling of stereo models in either parallel-line profile or radial-profile modes. In addition, interface equipment was designed to allow this instrument to drive an optical orthoprinter. This instrument employs optical image transfer to provide higher speed and resolution than is available with electronic printing techniques.

Related Developments

Bendix Research Laboratories have conducted several development programs in areas related to analytical stereoplotters. In one of these programs, computer control and automation equipment was developed for a three-stage stereocomparator. The computer control facilitates rapid measurements through helping maintain stereo-viewing during slewing between points, and averaging, editing, and correcting the measurements made. This instrument was automated in a manner similar to the automated stereoplotters. Presently, improved computer control facilities are being developed for another computer-controlled stereocomparator.

Another program involved the development of an error-correction system for a projection-type stereoplotter. The correction system consists of a precision measurement and control system and a digital computer which computes real-time corrections for the plotter based on initial orientation measurements. One computer can service several plotters. The correction system enhances the plotter's capabilities by correcting model deformation, eliminating precision orientation procedures, and enabling plotting from types of photography different from that for which the plotter was originally designed.

Development of an off-line orthoprinter has been initiated. The instrument will produce orthophotos by using digital terrain data which is gathered by a separate system. The inputs to this instrument will be a photograph and a magnetic tape containing data collected while profiling the model on an automatic stereoplotter such as the AS-11B-1. The off-line orthoprinter will use this data to scan the input photograph with a narrow slit of light. An optical system rotates and magnifies the resulting image, and the corrected image exposes a new photograph. The major advantages of the off-line optical orthoprinter are its high resolution, accuracy, and speed.

In 1967 Bendix completed development of the first completely field-portable line rectifier, the LR-1. This instrument, which weighs only 130 pounds, automatically removes the effects of camera tilts and panoramic sweep angles and produces rectified line drawings as used in making charts or maps. Bendix subsequently developed a more advanced portable line rectifier, the LR-2. In contrast to the LR-1, which uses an analog computer, the LR-2 uses a digital computer. It also has a new all-electronic input module using the Bendix Datagrid digitizer. The LR-2 system offers greater accuracy and flexibility than the LR-1 system.

Coherent optical research has been pursued for possible use in automated analytical stereoplotters. Coherent optical-processing techniques, which can provide parallel operation over an entire image area of interest, offer a potential means for greatly increasing the speed of image-processing systems. Application of these techniques to processing aerial photography for photomapping systems is being investigated. In initial work, the basic capabilities of a number of optical correlation systems were evaluated for application to image-matching operations. The characteristics of the optical systems were shown to be comparable, and in some respects superior, to those of electronic correlation systems. Bendix has made substantial progress in enhancing a basic optical correlator configuration by providing compensation for image distortion and generation of error signals needed in an automated instrument.

Progress has also been made in adapting coherent optical correlation systems to parallel operation and data output along a line or throughout an image area. An instant profile correlator has been conceived and experimentally tested. This correlator simultaneously displays the x-parallax along any selected line parallel to the y-axis in one of the photographs. The system employs a unique one-dimensional Fourier transform hologram optical correlator. It offers a potential approach for extremely high-speed measurement of terrain elevation information.

TRENDS

Analytical stereoplotter developments in recent years have continued some earlier trends and show signs of some new trends. It is reasonable to expect these trends will be largely followed in future developments.

Trends which can be noticed in the history of analytical stereoplotter development are:

* Improvements in image correlation for automatic plotting as new techniques are developed and new components become available. These improvements will provide increased automatic plotting speed and/or accuracy, and will require improvements in other portions of the system.
* Improvements in orientation methods and automatic aids to orientation as better methods are developed and adapted to analytical stereoplotters. These improvements will provide increased orientation speed and/or quality.
* Improvements in automatic editing of data, for both orientation data and plotting data, as improved techniques are developed and applied. These improvements will provide higher quality data with less manual intervention.
* Increased instrument versatility to handle different types of photography, correct output data for additional sources of error, and provide new data forms.
* Use of improved electronic technology as it becomes available to reduce cost and improve reliability and performance.
* Increased application of analytical stereoplotter principles to other photogrammetric instruments to obtain similar speed, accuracy, and effectiveness advantages.

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