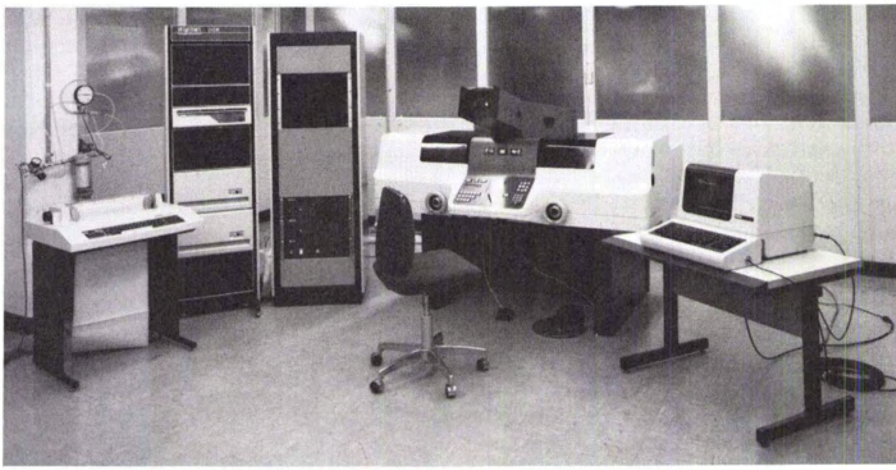

FRONTISPIECE. The Canadian Marconi ANAPLOT II system.

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The Canadian Marconi ANAPLOT II System

The ANAPLOT II System features a computer independent servo system and model refinement at any time.

(Abstract on next page)

INTRODUCTION

CANADIAN MARCONI COMPANY'S approach to the design of the ANAPLOT II analytical plotter reflects the history of the Company in electronics, the heritage of the ANAPLOT system, and the Company's commitment to photogrammetric development.

The analytical stereoplotter and the ANAPLOT system were both conceived and developed at the National Research Council of Canada. The Canadian Marconi Company has become a licencee of the patents, owned by the National Research Council of Canada, with the intention of making a commercial venture of the technology developed by the Council. In addition, Canadian Marconi intends to develop further both the hardware and software introduced by the Research Council.

The specifications of the instrument, designed by Canadian Marconi, was formulated in consultation with the National Research Council. The design was based on the intent of fully utilizing the technology developed by them, and the Company's desire to enter the field of photogrammetry, to produce a high precision analytical plotter which was competitive in the commercial market.

THE BASIC DESIGN PRINCIPLES OF THE ANAPLOT SYSTEMS

The basic components of an ANAPLOT system are an optical-mechanical unit, positioning servomechanisms, operator's control panel, a control computer with peripherals, and a plotting table. The optical-mechanical unit is the measuring and viewing component of the system and is linked to the dedicated computer, a PDP-11, by a general purpose interface and the PDP-11 UNIBUS.

Photostages are 23cm by 23cm in size, and move in two perpendicular directions. The photostages are driven by servo motors along drive shafts. Attached to the photostage assembly are linear encoder scales. The photostages, their drives, their measuring devices, and their supports are the main components of the analog system, and are the main factors that control the speed, accuracy, sta-

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ABSTRACT: *The ANAPLOT II analytical plotter system, manufactured by Canadian Marconi of Montreal, consists of a stereoviewer with an operator's control panel, an electronic interface, a PDP 11/34a computer, a hard copy terminal, and a VT-100 character display unit. Movement in the model is controlled by two handwheels, a footwheel, a joystick and the right footswitch. The PDP 11/34a operating system used with the ANAPLOT II is RSX-11M. The applications software, written in FORTRAN, includes four packages: (a) a basic applications package; (b) a control extension package; (c) a map compilation and digitization package; and (d) a non-conventional imagery package. The basic applications package contains five groups of programs: initialization, basic real-time programs, orientation programs, data collection programs, and support programs. Each of the other packages contain the programs in the basic applications package either in their original form, or in a modified form. High quality editing is a feature of the Marconi system. On the whole, the ANAPLOT II is a well integrated, comprehensive system, designed to meet the needs of the user.*

bility, and reliability of the system. Another feature of the ANAPLOT system is the feedback loop for the servo control which is used to position the axis. One advantage of the system is that the servo control is independent of the dedicated computer and a function of the interface hardware.

The operator controls are two handwheels, one for X and one for Y, a joystick for rapid X, Y movement, and a footwheel for Z control. Pulses from the movement of the controls are transmitted to interface registers which are the basic input to the computer.

The ANAPLOT systems use Digital Equipment Corporation PDP-11 computers. The speed of the computers used is adequate for all predictable uses of ANAPLOT, and the speed can be increased, if necessary, by incorporating a cache memory. The UNIBUS is the high speed link between the computer system components and the peripherals. In principle, the peripherals of the ANAPLOT systems include two removable disks, an interactive hard copy terminal, an interactive cathode ray display terminal, and, if required, a card reader, a paper tape reader and punch unit, and a magnetic tape drive. In addition, depending on the requirements of the user, other peripherals may be added. For instance, it is possible to interface to a main frame computer, or into a digitizer for general input into a spatial information system. The flexibility of the choice of peripherals is one of the key features of the ANAPLOT systems (Jacksic, 1979a).

The Electronic Interface Unit is the link between the UNIBUS and the system positioning apparatus. The operator's control panel is also essentially part of the interfacing electronics.

Two additional devices which can be incorporated into the ANAPLOT system are a plotting table and a position verifier. A plotting table can be either a flatbed or drum type. Any commercially available plotter can be incorporated into the system by means of the UNIBUS. The position verifier graphically records digital records, either directly in the field of view of the main optical train, or on an auxiliary cathode ray tube. The purpose of a position verifier is to display a record of the digital data collected from the stereo-model.

THE ANAPLOT II SYSTEM

THE STEREOVIEWER

The stereoviewer consists of three basic components, the stage plates, together with their drives and support mechanisms, the operator's console, and the optical system.

THE STAGE PLATES, DRIVES, AND SUPPORT MECHANISM

The stage plate support mechanisms of the stereoviewer consists of two independent sets of x and y carriages (Figure 1), a lower, inner x carriage and an upper, outer y carriage. The carriages are supported and guided by air bearings, externally pressurized to 82 to 103 kilonewtons/sq.m. The carriages move over an area of 24 cm by 24 cm and float, over the cast grey iron base surface, on a cushion of air. The upper y carriages support the photo stages, which are equipped with a system of spring loaded clips to hold the film or glass diapositives firmly in place. The Teledyne Gurley type 8716 encoder has a resolution of one micrometre and uses the Moiré fringe technique of counting. Abbe's principle is adhered to, which ensures that measurements made on the photostages are stable and of high precision. Tests with these photostages have shown maximum errors for a one year period (without correction) to be ±3 micrometres, and the RMS error of a single measurement to be ±1.5 micrometres.

The movement and position of the photostages along each axis is controlled by a D.C. closed loop

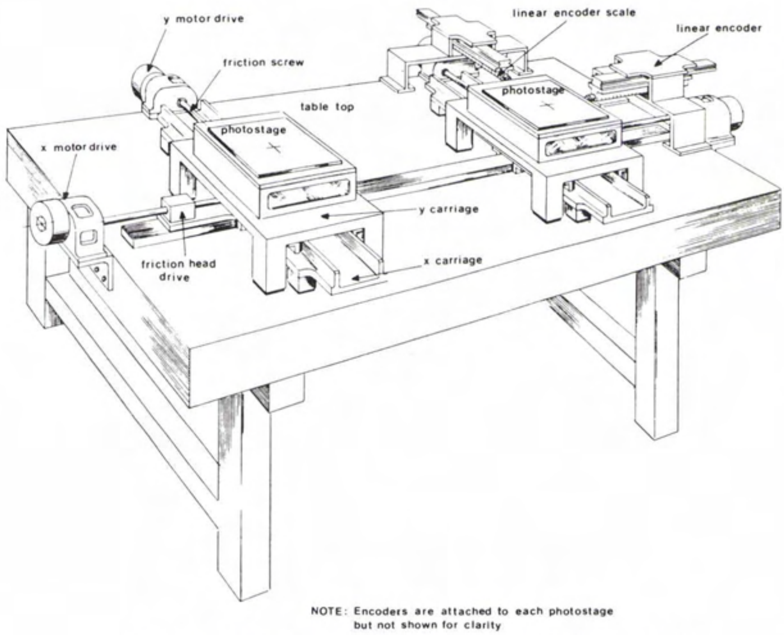

FIG. 1. Stage plates, drive, and support mechanisms of ANAPLOT II.

servo system (Figure 2). The system consists of a high torque, low inertia D.C. motor, a transmission system for rotary to linear conversion, a linear encoder, coordinate data registers, and motor drives. The servo motors are controlled by microprocessors in response to programmable inputs from operator controls.

The carriage drive system consists of a D.C. motor, a 3:1 gear ratio, a friction shaft, and a friction drive mechanism attached to the carriage. The friction drive is made of three roller bearings held against the friction shaft by springs and on a slight parallel offset to the shaft. As the friction shaft rotates, the friction drive, hence the carriage, is driven linearly along the shaft. The roller bearings are held against the shaft by the pressure springs; therefore, the mechanism will slip on the shaft should the carriage be held in position by a mechanical obstruction.

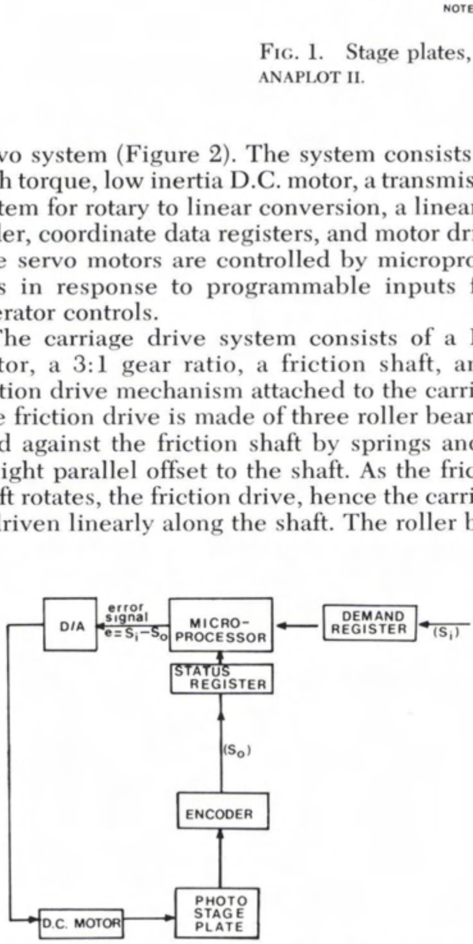

FIG. 2. The servo control loop of ANAPLOT II.

Limit switches are fitted to each axis, and prevent over travel of the photo carriages by removing power from the D.C. motors. Shock absorbers stop the carriages without affecting the mechanical integrity, and light emitting diode (LED) indicators on the control panel, augmented by an audio signal, alert the operator that a limit switch has been activated.

The stereoviewer mechanism is completely enclosed in a metal housing with a hinged top, giving easy access to the stage plates. The housing prevents all physical contact with the internal components of the stereoviewer, and supports the handwheels and control panel.

CONTROL PANEL

The operator's control panel, located below the level of the eyepiece assembly, provides the controls required for the operation of the analytical plotter system. The essential controls are arranged so that the operator does not need to divert his attention from the stereomodel. The console controls, shown in Figure 3, include the following: the main power switch; the air-on switch; photo-model control switch; X, Y, Z model coordinate or x_1, y_1, x_2, y_2 photo coordinate displays; a joystick for control of the photo carriages; two foot switches; 14 push buttons to the left of the display unit

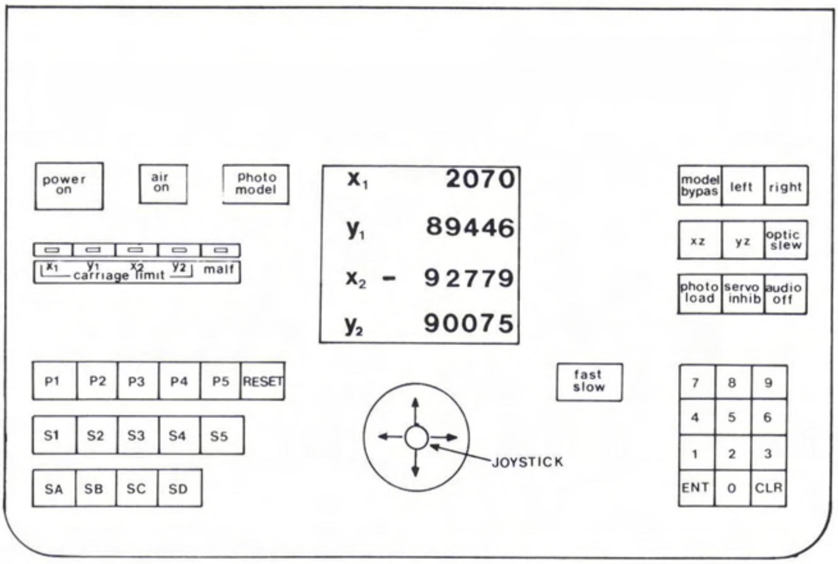

FIG. 3. The ANAPLOT II operator's console.

which have software functions; a number of buttons to the right of the display unit which have hardware functions, and 12 digital buttons which can be used to enter data into programs. The right foot switch is the parallax foot switch (mode selection switch) which, on depression, allows the parallax to be removed by *X*, *Y* handwheels from either the left or right photo, depending on whether the left or right hardware button is currently depressed. The left footswitch has the same function as the (SA) button and is used to record measurements.

The handwheels are placed in the traditional position to the left and right of the operator in the main body of the instrument. The footwheel, beneath the housing assembly, controls the Z motion. There are hardware switches to interchange the Z footwheel function to either the *X* handwheel or the *Y* handwheel.

THE OPTICAL SYSTEM

The optical train in the ANAPLOT II is fixed and views the stage plates from above. Thus, the diapositive plates or films are set emulsion up on the stage plate. Included in the optical train are computer controlled Pechan prisms and a zoom system, both driven independently by servo motors. The total magnification of the system varies from 6 to 24 times. The measuring mark is close to the stage plates between the first and second lens system. A circular measuring mark is available in three sizes—30 micrometres, 60 micrometres, and 120 micrometres—and the intensity of the measuring mark can be varied from opaque to luminous by means of a rheostat. The optical train has a left-right switch over for normal and pseudo stereoscopic viewing of a spatial model, and the same facility is used to ensure that normal stereovision is maintained in strip triangulation, when new photographs are placed in either the left or right stage plates.

THE INTERFACE

The electronic interface subsystem consists of six printed circuit cards, a set of D.C. power supplies for the electronic interface logic processing, and the necessary interconnecting cable harness. The interface printed circuit cards perform the following functions: (a) left photocarriage positioning control, (b) right photocarriage positioning control, (c) central control, (d) digital to analog conversion, (e) computer interface (I/O via UNIBUS), and (f) console display driver (Figure 4).

THE COMPUTER

The computer control is a Digital Equipment Corporation PDP 11/34a minicomputer with 256K byte MOS memory and a cycle time of 450 nsec. The PDP 11/34a includes memory management which extends addressing to 18 bits, allowing 248K for memory, plus 8K for I/O.

A floating point processor is an optional device integrated into the computer. The use of the hardware floating point processor in single and double precision (32 or 64 bit) floating point modes increases, by several orders of magnitude, the speed of the execution of arithmetic operations in comparison with the use of software floating point routines. The floating point processor fulfills the need for short response time required by the

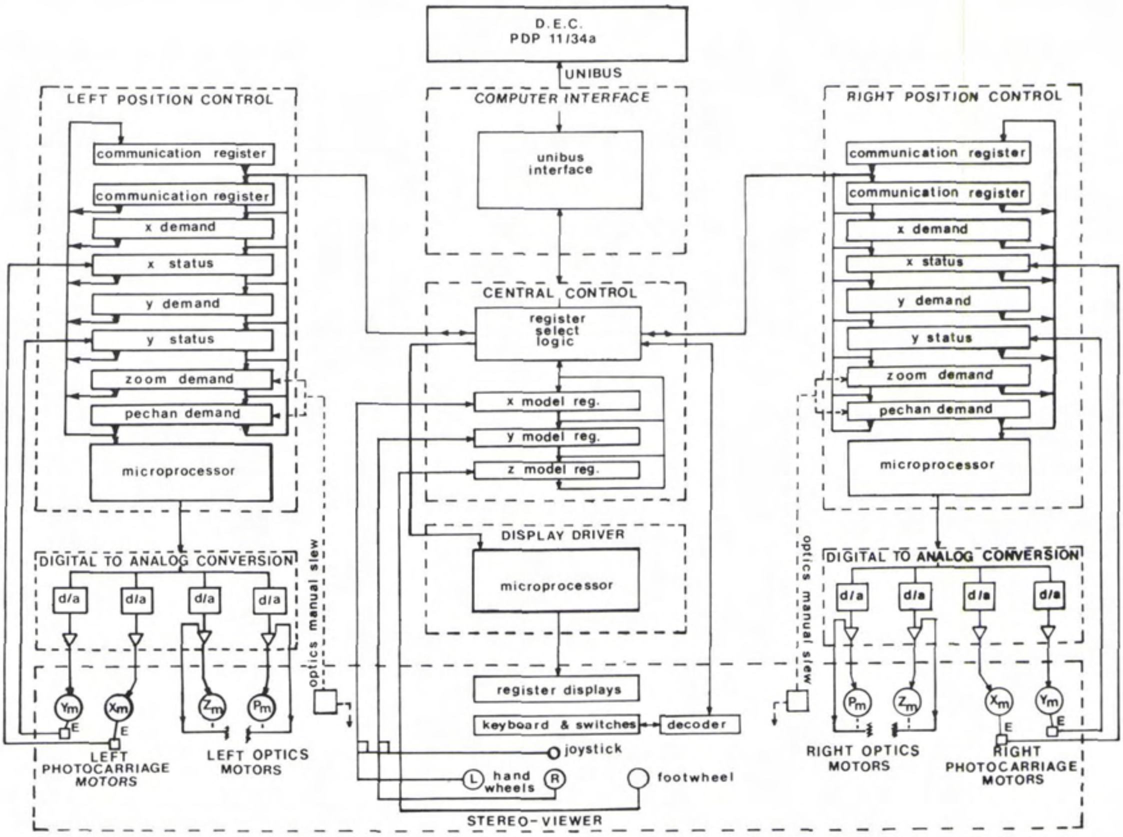

FIG. 4. The ANAPLOT II interface system.

real-time operations of the system, and offers the convenience of coding real-time operations in FORTRAN.

The link between the computer systems components and the peripherals is the UNIBUS. The maximum transfer rates of the UNIBUS is one 16-bit word every 400 nsec or about 2.5 million 16-bit words per second. However, in practice, the typical transfer rates, including average bus delays, is 1 million 16-bit words/sec (D.E.C., 1979).

The computer peripherals in the ANAPLOT II system, at present, are as follows:

Two RL01 moving head disk units with each cartridge having 5.2 million bytes of storage. In normal operation, one disk contains the program software, and the other disk the data files. The LA36 Decwriter II hard copy terminal and the VT 100 cathode ray character terminal are two input-output peripherals that may be used by the analytical plotter operator. The peripheral devices, incorporated into the system, permit flexible communications between the operator and the system, and efficient manipulation of data inside the system, which contributes to the speed and convenience of on-line operations.

Other computer peripherals may be added to the system depending on its use. For instance, a magnetic tape drive, a card punch, a paper tape punch, and additional disk packs could be added, or the system could be interfaced into a main frame computer for a multi-purpose land information system.

The total ANAPLOT II hardware system is shown in the Frontispiece.

SOFTWARE CONCEPTS OF ANAPLOT II

The ANAPLOT software is divided into two groups. First, the software operating system, and secondly, the applications software. The systems software is supplied by the computer manufacturer, and is provided for development, editing, compiling, link editing, and execution of the programs. In concept, the application software can consist of real-time programs, near real-time programs, and off-line programs (Jaksic, 1979b).

SOFTWARE OPERATING SYSTEM OF ANAPLOT II

The PDP 11/34a of the ANAPLOT II system uses the RSX-11M (Version 3.2) operating system. The RSX-11M is a real-time executive operating system, and is a small to medium size real-time multiprogramming system. The RSX-11M is a powerful disk based system, which allows concurrent execution of multiple real time tasks while simultaneously supporting program development. The system supports MACRO-11, FORTRAN IV, FORTRAN IV-PLUS, RPG II, BASIC-11, BASIC-PLUS-2, and COBOL languages, and may include data management utilities RMS-11, DBMS, DATATRIEVE-11, and SORT-11.

APPLICATIONS SOFTWARE OF ANAPLOT II

The applications software of ANAPLOT II may be divided into a number of packages as follows: A basic applications package, a control extension package, a digital map compilation and digitization package, and, finally, a non-conventional imagery package.

Each of the packages consists of a number of separate programs which are linked in a specific way to create the package. The basic applications package contains all the programs needed to create the other packages either in their original form, or in a modified form, and consists of the following set of programs which may be divided into five groups: Initialization, basic real-time programs, orientation programs, data collection programs, and support programs.

One feature of the ANAPLOT II software is that once information has been displayed on the cathode ray terminal, it is not lost and a hard copy can be obtained at any time if required.

BASIC APPLICATIONS SOFTWARE

Initialization. The initialization program avoids unnecessary repetition of entering data which are common to more than one photograph. The program requests information in a conversational mode for model restoration, for stereoplotter corrections, for radial correction file name, for the type of relative orientation, for principal distance, for negative or positive pictures, and for the first approximations for parameters of the rotation matrices. When the initialization is complete, the operator is prompted to load the photographs. One feature of the initialization program is the menu, which allows conditions to be preset and entered from file for each model.

Basic real-time programs. The main aim of the basic real-time programs is to read the coordinates from *X*, *Y*, *Z* registers, transform these co-ordinates into the photostage coordinates by the well known photogrammetric projection equations, and move the photo stages into positions defined by the transformed coordinates. All coordinates can be corrected for system and radial errors, as well as for the effect of film distortion (fiducial transformation) in the initialization program. The role of the corrections in the real-time program is to ensure the true position of the image point is addressed. The corrections in the real-time programs are the inverse of the corrections applied in the orientation programs. The real-time program also positions the optical components of the viewing system.

The real-time program is coded in FORTRAN, except for subroutines dealing with interface operations which are FORTRAN called MACROS. The frequency of reading, writing, and transforming the coordinates in frame photography is approximately 250 to 300 cycles per second.

Orientation programs. The inner orientation is initiated by one of the master switches (P1) on the control panel. The initial conversational part of the inner orientation program requests whether an offset principal point and a fiducial transformation are required. The operator is then asked whether a transformation is required. The operator is then asked whether a transformation should be performed on corner fiducials, side fiducials, or both. If corner or side fiducials are requested, an affine transformation is automatically chosen. If eight fiducials are chosen, the operator is given the choice of an affine or bilinear transformation.

The photographs are approximately centered, and then the measuring mark is automatically positioned, under computer control, in the vicinity of the fiducial marks. The fine positioning of the measuring mark is performed by the operator using the handwheels working in the *x*, *y* or *px*, *py* mode. A pre-set pattern is defined in a computer table for measuring the fiducials, and if a fiducial transformation is to be performed, the calibrated coordinates of the fiducial marks must be stored first. When the final point in the pattern has been measured, the program automatically computes the transformation parameters and the coordinates of the principal point and positions the measuring mark at the new photostage coordinate origin.

Two modes of relative orientation are available on ANAPLOT II, independent orientation and dependent orientation. The relative orientation program is activated by the (P2) switch on the operator's control panel.

The initial part of the relative orientation programs is again in a conversational mode. The operator is prompted for the base length, the point pattern in which the parallaxes are to be cleared (six, nine, or free point modes are available), and, in dependent orientation, the image to be oriented and whether serial (by computer) or manual (by operator) point identification is required.

The data collection part of the program automatically positions the measuring mark in the region of the first point in the selected pattern. The actual point is decided by the operator, and the parallaxes are removed by the operator and recorded by pushing the software switch (SA) or the left footswitch.

One of the advantages of the ANAPLOT II on-line relative orientation is that the model, once formed, can be viewed while the basic real-time program is operating, and, if residual parallax is seen or known to exist from the residuals on the computer printout, given as soon as redundancy occurs in the measurement, the operator has the option to accept the model as it is, or he can introduce measurements to refine the model. The critical piece of technology which allows this refinement at any time is the right foot switch and the way it works with the software in ANAPLOT II.

In relative orientation, the parallaxes are cleared for the first five points in the comparator mode with the right foot switch depressed, but computer control is used to drive between the points at which the parallax is to be eliminated. After the measurement of the fifth point, the model is constructed and viewing the model is achieved by the basic real-time program. At this point the operator has two choices. First, the formed model may be considered adequate and additional measurements may be made under computer control of the basic real-time loop (plotter mode). These additional measurements contribute nothing to improving the model and any inadequacy in the model is reflected in the additional measurements. The second choice is to add additional points in the comparator mode with the right footswitch depressed. In this case, any additional point measured is added to the condition equation of the least-square solution and used to update the orientation parameters. This results in a refinement of the model, which may or may not improve the model depending on the quality of the additional measurement.

After the orientation parameters and residual parallaxes have been computed and displayed, the ability to delete, add, or replace points is available. The parameters and residual parallaxes are then re-determined without measuring all the points again.

Absolute orientation is achieved by storing a file with control coordinates on disk. The determination of the absolute orientation parameters can be achieved either with control points with full control (E, N, H) or with partial control (E, N) or height only. Analytical absolute orientation is a seven parameter, or linear three-dimensional conformal transformation. The seven parameters are scale, K, Φ, Ω, and three translations in the X, Y, and Z directions, respectively. An iterative solution determines the parameters K and scale from points of known position, and Φ and Ω are determined using points with known elevation. The remaining three translation parameters are determined by using the center of gravity coordinates of the model points and the coordinates of the center of gravity of the corresponding control points.

The initial conversational part of the program requests the control file. The control file is created with a utility program. The operator has a choice to use such a file, or to indicate a no-file condition and enter the control values at each point recorded.

The data collection procedure uses a real-time subroutine to record model coordinates of control points. After correct pointing at a control point, the operator initiates recording by the (SA) switch, or the left foot switch. The data collection routine prompts the operator to enter the point number. When the end of data collection is indicated by the operator with the (SD) switch, the recorded points are matched with the control points in a file and an optional utility routine allows entry of the known approximate value of pitch and tilt for convergent or high oblique photography. In addition, an editing feature exists in which ground control points can be added, deleted, or replaced.

Once the parameters of absolute orientation are determined, there are two ways in which they can be used in real-time compilation routines: model to photo coordinate transformations $X, Y, Z, \rightarrow x_1, y_1, x_2, y_2$, and model to ground coordinate transformations $X, Y, Z \rightarrow E, N, H$.

Another orientation program exists, a universal orientation program which performs a simultaneous solution for both relative and absolute orientation at the same time, based on the well known collinearity equations, and is useful in close-range photogrammetry.

Another feature of the ANAPLOT II software is a model restoration program. In the general initialization program, the operator is asked if he wishes to restore the model. The model can be restored in two ways. First, after the operation of the instrument is interrupted and the photographs are not removed, and second, if the pictures have been removed from the photostages and require remeasurement at a later date. In the first case, the data for model restoration is transferred from a file into memory locations used by the basic real-time program. In the second case, the fiducials have to be remeasured, a new fiducial transformation is defined, and the exterior orientation parameters are retrieved from disk and used by the basic real-time programs.

Data collection programs. Data collection programs are those programs which are used to collect and process data from an oriented stereomodel. The main component of data collection programs is the real-time program, under which measurements in the stereomodel can be performed. Any data collection program makes extensive use of the slave switches to perform various functions. For example, in digitization, switch (SA) starts recording, switch (SB) causes a pause, (SC) resumes execution after a pause, (SD) terminates execution, and (S4) creates a new file.

Digitization is the essential form of data collection. Both discrete point digitizing and line digitizing are available as part of the ANAPLOT II software. Both digitizing programs have an initial conversation with the operator.

In point digitizing, the operator specifies the name of the file for storage, the point number, and *X*, *Y*, *Z* co-ordinates. The type of coordinate to be stored (photo, ground, model) and the mode of point identification (assigned by operator, or sequential by computer) are also supplied. While the real-time program is running, the operator selects the point and records the coordinate by the (SA) switch, or the left foot switch.

In line digitizing, the operator specifies the storage file name, and indicates the mode and frequency of sampling. Two sampling modes are available, a space dependent one and a time dependent one. In the space dependent mode, the measuring mark moves by a specified increment in model space between recorded coordinates. The operator specifies whether two-dimensional or three-dimensional increments are required. The time dependent mode samples the registers after a specified number of cycles through the real-time program. The default is every cycle. There is a choice of two sampling routines in the time mode. One routine merely records one point at each sample interval, while the other records repeated coordinates on the same point. This allows playback of the gathered information at variable speeds.

Support programs. There are two main groups of support software. The first group contain programs concerned with off-line computations. For example, programs pertaining to the preparation of correction tables, ground control files, correction files, and orientation files, and programs for the manipulation of files generated by the compilation programs.

The second group contains on-line programs for testing and calibration of the system and system components. Another program in this group is for testing the positioning and measuring assemblies. It drives the photostages to the intersection points of a calibrated grid plate and, when positioned under the measuring mark, records the contents of the status registers. From a large sample the program derives statistical estimates for the assessment of the positioning devices. A third program tests the overall performance of the system and the stability of its calibration, and in addition generates correction tables for the systematic errors of the system.

This group also contains a number of utility subroutines used in all programs. Some of them are as follows: "help" subroutines, I/O error detection and correction subroutines, data entry routines, verification and modification programs, file checking subroutines, and other useful housekeeping routines.

Control extension package. In offline analytical aerial triangulation there is no feedback system; therefore, the possibility of eliminating errors and blunders, especially in identification, is small. In conventional analytical triangulation, several reruns are used to clean the data from gross errors. This is a costly process in time and money for large blocks. The least-square adjustment distributes the error throughout the block, and these blunders or gross errors are difficult to detect. For these reasons, the triangulation and adjustment of large blocks is often treated in two stages, a cleaning process to detect blunders with remeasurement of points, if necessary, and a final rigorous adjustment stage (Kratky, 1979).

On-line aerial triangulation can be performed in one of two ways. First, on-line triangulation with off-line adjustment, and second, on-line triangulation with on-line adjustment. The first approach is more likely to be used in practice, and, with the ANAPLOT II aerial triangulation program, the emphasis has been placed on data collection thoroughly checked for the presence of gross errors and blunders.

The ANAPLOT II aerial triangulation is modular and, like the other programs on the ANAPLOT II system, is written in FORTRAN. The triangulation program uses three basic programs engaged in a bridging loop: initialization (done only once)→inner→depend→inner→depend. Termination of the loop is by the slave switch (SD) on the ANAPLOT console.

The initialization, inner orientation, and dependent relative orientation are essentially the same as described in the basic applications package with minor modifications and will not be dealt with at any length here. Only the essential differences will be emphasized.

In the relative orientation of the first model, the first five points are measured in the comparator mode without computer control, except that the measuring mark is driven to the approximate point. As each point is measured, the photo coordinates are printed out, and beginning with the first redundant measurement, the least-squares solution yields the standard error of unit weight and the number of iterations for convergence, and these values are printed. This solution provides a continuous, almost instantaneous, update of the orientation parameters with each new entry. Pattern A or B can be followed by any number of additional orientation points in the manual-free mode. However, these points have to be numbered by the operator. The coordinates contain corrections for all three sources of errors as mentioned above, but when the photo-coordinates are stored on disk, only the systems corrections are included, as an off-line adjustment program may correct for the other two in a different way and this flexibility should not be lost.

Tie points are an important feature in aerial triangulation and are needed to ensure a good fit and continuity between consecutive stereomodels. Tie points are defined in the first model with respect to the subsequent model.

The procedure for the subsequent models is almost identical to the first. In the conversation only one photo number is requested, while two photo numbers are required in the first model, but residuals for tie points are printed after the first model. Orientation of the new model is now solved simultaneously with scale transfer as an additional parameter. That is, six elements are solved simultaneously (Kratky, 1980).

In the ANAPLOT II system, the tie point can be selected during the operation without provisional identification and marking. In order to measure a tie point in the current model, the computer positions the appropriate photo carriage from coordinates determined from the previous model, and holds it there by blocking any manual control action until the point has been recorded. As long as the configuration of the tie points is standard, the computer automatically numbers the points. One of the features of the ANAPLOT II software is that only six tie points are used, three in the old model and three in the new one. If pattern A is chosen, the six points measured to clear the parallax in the model may be the tie points, and if pattern B is used, the six tie points may be the six points in the two outside columns of points.

One of the most important parts of on-line bridging is the editing process. Anytime after a suitable number of points are measured, an immediate breakdown of y-parallaxes can be requested. The points are listed in measured order and the discrepancies in parallax shown. From the parallaxes listed, it is possible to add, reject, or replace points in models. After the first model, additional values dx, dy, dz, which represent the discrepancies in tie points, are given. In editing a tie point, if it is one of the first three, the position of the leading photograph is held and only parallaxes of the other photograph are changed. No tie point can be totally rejected; a new measurement must always follow.

After the completion of the editing processes, the operator is requested to replace the trailing photograph. The other stage plate is placed in a position where it cannot be removed, and the trailing picture replaced with a new photograph, which now becomes the leading picture in the subsequent model.

If map compilation is to be performed in an analytical instrument, pass points are not needed. However, if compilation is to be conventional in an analog instrument, the function of pass points cannot be eliminated. Pass points do not have to be common to adjacent models; they can be identified in a single model as independent groups. The other alternative is to use the tie points as pass points, or réseau crosses, or any other artificial mark.

The pre-triangulation marking and identification of lateral tie points is also unnecessary (Kratky, 1981). After the strips have been formed, the cross ties can be measured by forming stereopairs from photographs belonging to adjacent strips by rotating the base by 90°. The measurements take place in the comparator mode as the number of points in the normal 20 to 30 percent sidelap is inadequate to support accurate photogrammetric computations.

Cross-pair measurements require new inner orientation measurements with an auxiliary transformation so that all the measurements are transformed into the original coordinate system of each photograph, and are compatible with the data files established in strip formation.

The search for tie points which are available for cross ties is limited to effective overlaps, as shown in Figure 5. For example, for cross pair 10-32, the dotted area in models 9-10 and 10-11 in the data files are searched for available points. Any point found in this area is retrieved and transformed into the new rotated coordinate system. The point position is blocked in the left picture (10 in example), and the operator measures the point stereoscopically in picture 32. When all the points have been exhausted in picture 10, photograph 32 is searched until the search is exhausted. In addition, more tie points may be chosen and converted into the original system by the transformation parameters for that particular picture.

In the triangulation of a long strip there may be a number of interruptions to the on-line operations. In such instances, it is necessary to suspend the operations temporarily, and to continue with no loss of data or remeasurement of points later. Pro-

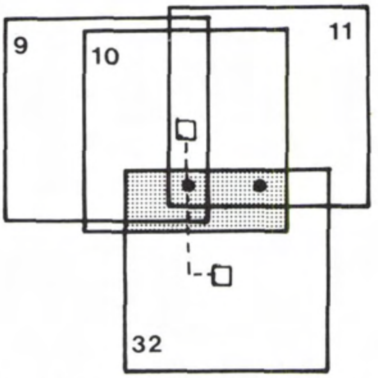

FIG. 5. Cross ties in the ANAPLOT II control extension program (after Kratky, 1981).

vided that the current pictures remain in their stages during the interruption, which is normally between models, the file on disk and its contents can be read back to core in order to restore the model to its original orientation at the time of interruption.

A second situation occurs when it is necessary to reset a model which has been removed from the stage plates. This is usually done if a control point has to be remeasured because of misidentification. The reset program searches the files and finds all the necessary information needed to reset the model. Information on the conditions of the original solution must be re-entered from the computer terminal. A new inner orientation has to be performed, but these are the only measurements necessary for the reset. The old set of fiducial measurements is used as control to transform the new set into the old coordinate system. The transformation parameters then relate the new physical situation with the old one, and the restored model is optically and numerically identical to the old one except for a few micrometres. The reset model can be checked and remeasurement carried out as needed.

Map compilation and digitization package. The map compilation and digitization package contains the basic applications software package, but it also contains a number of additional programs, such as contouring, profile or cross sectioning, playback, and digital terrain modelling, all of which are special applications of the digitization and basic photogrammetry programs.

Contouring is a special form of line digitizing. Both time and space modes of recording are available. The operator specifies a rectangular or general contouring window by defining the lower left and upper right points in the model system, and in the real-time operation, the measuring mark is constrained in this window. The operator starts the digitizing on the boundary of the window by pressing the (SA) switch, or the left footswitch. At the start of each record, the contour elevation is entered as the header of the record. Recording procedes until the operator terminates recording by the (SD) switch, or the measuring mark reaches the edge of the window.

Profile or cross-section digitizing is performed in conjunction with the basic real-time program. A time dependent sampling routine is used. A window can be defined in the same way as the contouring program. Each profile may be fixed in the direction of the X axis of the model system, or the Y axis, or have an arbitrary direction in the X-Y plane. In the latter case, the operator defines the direction of scan by pointing at two points and recording their model coordinates. The orientation of scan is determined from the two points. The X handwheel controls the motion of the measuring mark along the scan direction, and, by use of the YZ switch on the operator's console, the Y handwheel controls the elevation of the measuring mark. Digitizing of profiles may be individual or in groups. In digitizing parallel groups of profiles, the measuring mark hits the boundary of the window at the end of the profile, and it is automatically positioned at the beginning of the next profile. The distance between profile lines is requested from the operator by specifying the distance by two measuring mark positions. This is performed in the conversational part of the program before the profiling commences.

Playback is a program available on ANAPLOT II to replay any file created by the continuous digitizing routines. This feature allows the operator to check that the information has been recorded correctly before proceeding to the plotting stage. The playback program is invoked by the slave switch (SA) and the operator specifies the file name from the terminal. The data file, which is stored as increments, is transformed to model coordinates and fed into the X, Y, Z registers. The real-time loop reads the registers, transforms the model coordinates into the corresponding photo coordinates, and moves the stage plate through the model space in the same way as the data was digitized.

The digital terrain model program is still in its infancy and more advanced developments are planned in the future. The program, as it stands, is composed of routines for window definition, grid definition, mode of height recording, and file formation. The digitized region is defined by an analytical window similar to the contour or profile digitization packages. The grid pattern may have an arbitrary orientation in the window. In the conversational part of the program, the spacing along the grid line is defined by model coordinates of two points, selected and measured by the operator. A third point, chosen by the operator, defines the spacing between the grid lines.

There are three different modes of recording a terrain model. First, the measuring mark is automatically positioned on the grid point and each time records the Z value by pressing the (SA) switch, or the left foot switch. Second, the program can cause the measuring mark to pause at each grid point for a fixed period of time, determined in the conversational part of the program, before automatically recording of the point. This allows the operator time to position the floating mark; and, finally, the recording may take place only after there has been no change of the Z coordinate for some fixed length of time.

Non-conventional imagery package. The non-conventional imagery package of Canadian Marconi software, at present, consists of panoramic photography.

Panoramic photography is restituted in the ANAPLOT II by using programs which are modifications of the programs contained in the basic applications software package. As well as all the programs contained in basic application software, there are, in addition, contouring and profiling programs available which provide output in the same manner as described in the map compilation and digitization package.

The distortions present in panoramic photography are considerably different from frame photography. The concept of an analytical solution required to obtain restitution of the panoramic photographs, which is used in the Marconi software, has to be attributed to Case (1967). In Case's paper the idea of converting from the cylinder to a simulated frame photograph was first expressed, together with the possibility of an iterative solution.

The formulation of the solution used in the panoramic software was performed at the National Research Council of Canada and was based on Case's original idea (V. Kratky, personal communication, 1981). The solution used requires considerably more transformations than frame photography. The additional mathematics required slow down the basic real-time loop. However, it is still possible to obtain a solution in which the stage plates move smoothly and show no signs of jerking. The fact that unconventional solutions are used in no way deteriorates the photogrammetric model or the measurement process.

Conclusions

The Canadian Marconi ANAPLOT II analytical plotter is a third generation instrument whose design and construction are characterized by the implementation of the latest developments from photogrammetric, computer, and systems technology. The goal of the design and construction has been met with a well integrated system which is universal, modular, accurate, fast, reliable, stable, flexible, and easy to use.

It may well have been these advantages which prompted Ian Dowman, reporting on the 1980 International Society for Photogrammetry Congress in Hamburg for the 1981 April issue of the *Photogrammetric Record*, to state, "The most impressive instrument of the show was the Canadian Marconi ANAPLOT, a highly flexible, powerful, and complete system. . . ."

ANAPLOT II is just one of a number of pieces of photogrammetric equipment which are being developed at Canadian Marconi. With future developments, the quality and design considerations of the technology in ANAPLOT II will be maintained, and improved, to satisfy needs of the user.

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