Photogrammetria, 33 (1977) 1—18

SOFTWARE ASPECTS IN DESK-TOP COMPUTER-ASSISTED STEREOPLOTTING*

EGON DORRER

Hochschule der Bundeswehr München, Munich (F.R.G.)

(Received November 30, 1976)

ABSTRACT

Dorrer, E., 1977. Software aspects in desk-top computer-assisted stereoplotting. Photogrammetria, 33: 1—18.

The paper covers an interactive data-acquisition and processing system enabling computer-assisted on-line processing of photogrammetric stereomodel coordinates. In view of computer costs and simpler programmability, the problem has been solved for desk-top computers. The levels of computer assistance and general programming aspects for desk-top computers are discussed in detail. Derived from that are some important requirements for these types of computer.

As an example, the Computer Assisted Stereo Plotting Program system (CASP) is explained, developed for Carl Zeiss of West Germany. CASP's present hardware requirements are supplied by the Hewlett-Packard 9810-A calculator with 111 data registers and 2036 instructions, and by either the simple DIREC-1 electronic counting and control unit or the more versatile ECOMAT-12, both of them manufactured by Carl Zeiss.

The *basic software* of CASP consists of 3 program modules:

(1) STATRECORD serves for real-time computations and display of model or ground coordinates (cycling time 0.1 or 0.2 s), for the definition, generation and input of point identification numbers and for the recording of processed single-point observations.

(2) LISTMANIPUL allows the manipulation of the 2 ground-control memory lists, such as deleting and inserting of points, or reduction or expansion of the control type.

(3) DYNRECORD serves for the continuous measurement of linear features with automatic triggering of recording at intervals of time, distance or coordinates, as well as the definition and input of feature codes.

The *application software* consists of 2 modules:

(5) ABSOLOR-1 for an equipment-invariant absolute numerical orientation with spatial similarity transformation. A high degree of interactivity is achieved with error display and LISTMANIPUL. Vertical, horizontal and spatial control points may be used concurrently.

(6) ABSOLOR-2 for determining equipment-specific setting elements for the absolute orientation in the stereoplotter.

The program system developed approaches the limits and capabilities of the desk calculator employed. Additional and future alternative solutions are outlined.

---

* Presented paper, Commission II, 13th International Congress for Photogrammetry, Helsinki, 1976.

1. INTRODUCTION

The expressions "computer assistance" and "computer control" have, in principle, been known in photogrammetry for two decades. However, the development of the Analytical Plotter initiated by Helava (1958) at the National Research Council of Canada and carried on by Bendix Research Corporation (U.S.A.) has not until very recently found the acceptance in photogrammetric circles that had originally been expected. It has only been in recent years — generally speaking, after the Ottawa Congress in 1972 — that a partly much simpler type of computer-assisted photogrammetric data acquisition and processing has begun to impose itself in addition to the technique mentioned above. Although it had been advocated for quite some time by Jenoptik (Hofmann, 1961), the on-line use of a digital computer with an existing photogrammetric stereoplotting instrument has become attractive for practical use only recently by virtue of the advances in the field of digital technology (Dorrer et al., 1974). All of a sudden, many photogrammetric plotting organizations are demanding the connection of an already available stereoplotter to a computer usually also available. See, for example, Kröll (1974), Wood et al. (1974), Dorrer et al. (1974), Berger et al. (1974).

By comparison with pure data-acquisition hardware, such as is offered on the market, a system entirely based on software presents the considerable advantage of additional and extremely flexible data processing. In other words, measurements can be carried out in a controlled manner and can be processed interactively to intermediate or final results; real-time transformations and real-time computations become possible; plotting operations such as absolute orientation, determination of perspective centers, connection of models, formation and adjustment of strips can be accelerated and objectified.

A computer-assisted stereoplotting system is a digital data-acquisition and processing system consisting of a photogrammetric stereoplotter and a digital computer connected to it via an interface. In the simplest case of an "open loop" (see Fig. 1; solid lines), the computer automatically receives certain observational data from the plotter and processes them automatically and/or

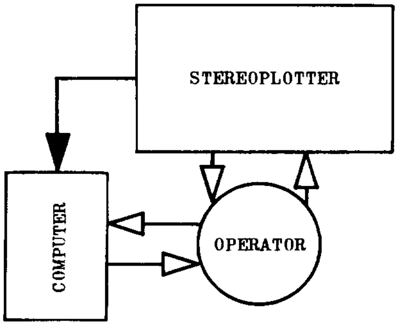

Fig. 1. Open-loop computer-assisted photogrammetric data acquisition (principle).

according to the instructions of the human operator. Contrary to a computer-controlled analytical stereoplotter ("closed loop"), the computer here only "assists" or "aids" the operator. In a broader sense, however, computer-assisted stereoplotting also consists of a closed information loop (Fig. 1; open lines) if the human operator is included in the system as well: it is he who calls the programs, reads or enters data and makes decisions.

A general study of the on-line use of digital computers in photogrammetry, particularly with regard to rather computer-independent programming, is indispensable also in conjunction with desk calculators. However, due to the frequently striking differences between the different models and makes, studies of this type can be applied to desk calculators only to a certain extent. A good interactive and computer-assisted data-acquisition and processing system is above all distinguished by the fact that it outputs the correct information or demands it from the human operator at the right moment. Optimum basic and user software can be attained only by a successive adaptation to the problems concerned, the type and capacity of the desk calculator, the general wishes of the users, the recording and stereoplotting equipment as well as the interactive flow of information.

2. LEVELS OF COMPUTER-ASSISTED DATA ACQUISITION

In principle there are three different levels of computer-assisted data acquisition, dictated by the type of digital computer employed.

2.1 Large external computer via terminal

This offers the advantage of high storage capacity, simple user programming (e.g. in ALGOL, FORTRAN, BASIC, PL1, APL) and, except for the terminal itself, the absence of maintenance cost. However, there are serious drawbacks: low data-transmission speed; long waiting periods during rush hours; high costs for telephone, computer time, use of storage and terminal fee. Due to these reasons such a system cannot be recommended today for actual photogrammetric production. It does, however, offer considerable advantages for research and development.

2.2 Minicomputer

The advantages of this type of computer are: relatively low costs, at least as far as the central processor is concerned; very high computing and data-transmission speed; extremely flexible and computer-oriented programming languages (assemblers); a great potential of peripheral equipment; practically unlimited expandability; high compatibility between different types of computer; availability of general and real-time operating systems. Although there are only minor genuine disadvantages, these may have all the more weight. Minimum configurations (e.g. with 8K 16-bit word memory) allow programming exclusively in the computer's assembly language which, however, cannot easily be understood without a sound background in computer structure. It may therefore become necessary to employ a separate programmer. The use of higher programming languages such as FORTRAN calls for considerably higher storage capacities (e.g. 32K); but in practice, suitable compilers can only be used economically and efficiently by means of magnetic-disk and corresponding operating systems. Minicomputers will be used increasingly for process control in photogrammetry and cartography in view of the aforementioned advantages of its high degree of maturity and of increasing complexity of the tasks demanded by practice (Tsivos and Dorrer, 1975).

2.3 Desk-top computer

This type of calculator is becoming ever more popular, particularly among non-specialists in the computer field. While a minicomputer is a genuine computer *en miniature* that is based on logical grounds and on the binary system, a desk-top computer is a rather more personal and interactive computing aid not carrying the logics to extremes. The advantages are known: the calculator has its own keyboard; a special keyboard programming language can easily be learned; in the case of larger calculators BASIC or APL interpreters are available; low price; simple maintenance; direct data input and output in the decimal system, therefore a high degree of use-orientation; usually several display registers or a built-in screen promoting interactivity between man and machine. Peripheral equipment is likewise offered by the calculator manufacturers, but only very limited compatibility exists between the different makes of calculators and peripheral units. It is, however, relatively easy to connect in-house built interfaces to a desk-top computer, hardware and software-compatible instructions generally being made available by the calculator manufacturers.

A disadvantage may, above all, be the limited storage capacity in the case of minimum configurations. Moreover, the low computing and data-transmission speed may prevent certain real-time uses. Small organizations will undoubtedly find such a desk calculator system a most economical solution.

3. POPULAR TYPES OF DESK-TOP COMPUTER

In view of the obvious advantages desk-top computers offer the non-specialist in computer technology, the usefulness of some of the most popular types for photogrammetric purposes will, in the following, be discussed in greater detail. Of the many companies manufacturing desk-top computers, only Hewlett-Packard and WANG are considered here. Hewlett-Packard offers five sophisticated and partly very popular calculator types in its 9800 Series together with a larger number of compatible peripheral units. The WANG company makes three different models.

The HP-9830 and WANG-2200 calculators are top models as regards general aspects, efficiency and simplicity of their programming language (BASIC), operator comfort and expandability. The advantage of the WANG-2200 is, above all, its large alphanumeric display screen which furthers interactivity. The two computers with corresponding peripherals can be recommended for organizations processing a large amount of data, and developing their own programs. Due to the complexity of the BASIC interpreter, data-transmission speed is lower than in other models. If the calculator is used on-line with a photogrammetric stereoplotter, this may, under certain conditions, result in intolerable bottlenecks in continuous data acquisition.

By comparison, the models HP-9810 and WANG-700/720 or 600 have intentionally been designed along simpler lines so that higher computing and transmission speeds can be obtained although at the expense of operator comfort and simplicity of their programming language. The primary advantages of the HP-9810 over the WANG-700/720 are the following: three display registers instead of two; separate program and data memories (which may, however, also be a drawback); additional function blocks (ROMs) are independent of the working storage. The WANG-700/720, on the other hand, has 256 definable function keys and a built-in magnetic-tape cartridge unit. These two desk calculators come closest to a control computer. Especially the HP-9810 is well-suited for computer-assisted photogrammetric tasks. The improved HP-9815 model is more versatile and has a new type of very fast built-in tape cartridge with two tracks. However, it has only one display register.

The successor to the HP-9820, viz. the recently introduced model HP-9825 offers an extended, very versatile algebraic and problem-oriented programming language (HPL), a very fast built-in tape cartridge like the HP-9815, and it is the only desk-top computer with an external interrupt feature.

The strong point for the more expensive BASIC models is their high flexibility regarding development, modification, correction and testing of complex and long programs, such as are required, for example, for rigorous orientation techniques (Harley, 1971; Wood, 1974). However, once the software is available and need not be changed any more, this strong point loses its importance so that for routine work the less expensive models become more attractive economically. See also Jeyapalan (1974), Keene (1974) and Dorrer (1976).

4. ON-LINE PROGRAMMING OF DESK CALCULATORS

To an even greater extent than in conventional off-line programming, interactive programs can be conceived and developed in different ways, depending on, which criteria are considered to be of primary importance. This generally holds for all levels of computer-assisted data acquisition, but it applies above all to desk-calculator systems. In detail, the following boundary conditions and aspects deserve particular attention.

4.1 Storage capacity

Extensive program systems generally have to be available on external storage media. In the case of desk calculators, these are magnetic cards or cartridges, occasionally also floppy disks. Only a part of these can reside in the working storage at any given moment (overlay technique). This is why the program systems have to be of modular design. Interfaces must be designed very carefully in order to ensure that the data will be transmitted logically from one module to another. Experience has shown that minimum configurations (for instance, HP-9815 with 427 program steps and 10 data registers) do not suffice for photogrammetric uses. The complexity of the mathematical relationships, the necessity of storing long lists of points in a buffer zone and executive programs controlling the system require at least 1500 program steps and 100 data registers.

4.2 Computing and data-transmission speed

In general, desk calculators are slower than minicomputers by a factor of 10 to 100. As a result, critical bottlenecks must be expected, above all in the case of the dynamic (or continuous) recording of lines. Every real-time part of the program should therefore be programmed towards minimum computing time, even at the expense of the storage space required and the elegance of the program. For the same reason, as few subroutines should be used as possible, and direct jump addresses should be employed instead of labels. Direct addressing is preferable for small loops (e.g. $n = 4$). Programs not restricted by time constraints should be designed so that they require only a minimum of storage space.

The logic and speed of a computer by themselves would be sufficient to take care of the entire data-transmission process from the stereoplotter to the computer. This is particularly true for the interrupt logic of a minicomputer. Since a desk calculator does not have this interrupt feature, it has to request the data on its own by processing signals by a so-called handshaking method. In view of the limited compatibility between calculator types and makes, maximum data-transmission speed can only be attained at the expense of the independence of the calculator from interfaces. The more general such a handshaking technique is in its hardware aspects, the slower the data flow and the bulkier the software.

4.3 Programming deadlines

If deadlines are very short, on-line program systems to be developed cannot be expected to be of nearly optimum design. In view of the large number of possible approaches and solutions, such an optimum program can be obtained only by successive approximation. Development of an easy-to-use software system is at least as difficult, time-consuming and frustrating as that of the corresponding hardware.

4.4 Peculiarities of programming language

The more expensive a desk calculator is, the greater is the operator comfort, the more general its programming language and the greater, above all, its editing capabilities. Problem-oriented dialog languages such as BASIC and APL are preferable because development of an extensive program system with a multitude of input and output conditions is a very repetitive process requiring continuous correction. Thus, programs written in BASIC can without difficulty be improved, modified or exchanged with other calculators. However, desk calculators based on BASIC or APL are slower than others using a calculator-oriented programming language by at least a factor of 3. In view of the above considerations, simpler desk calculators should therefore be given preference for computer-assisted data acquisition; this is particularly true if editing functions are incorporated, such as the addition and elimination of instructions, automatic correction of all branching addresses, error messages, introduction of break points for trouble shooting, etc. At present, the HP-9825 calculator comes closest to this concept.

4.5 Available peripheral equipment

In view of different format and user requirements, the program system on a desk-calculator level can hardly be kept so general that it would apply to all relevant peripheral units. In cases of doubt, such a system will therefore be designed for a medium hardware configuration, for example magnetic cards, narrow-format printer and, possibly, tape punch. Typewriter output already calls for extensive formatting commands, i.e., more program steps. The most suitable choice seems to be a magnetic-tape cartridge because it allows programs and data to be intermittently recorded in a very simple manner. Here also, however, at least 40 to 60 data registers are required as buffer storages because of the necessity of file definition. The disadvantages of the desk-calculator level are particularly evident in data transmission to peripheral equipment. As Schwebel (1976) has shown for the ECOMAT-12, the digital computer can be relieved of these particular tasks by shifting essential parts of the recording phase to a separate control unit. Thus the software can be limited to the more complex phases of true data processing.

4.6 Operator keyboard

One of the advantages of a desk calculator is its operator-oriented keyboard. Although keyboards vary from calculator to calculator, they still have many things in common: number keys, program-instruction keys, built-in function keys, editing keys, user-definable function keys. In order to leave the operator as much freedom from the keyboard as possible, the most frequently required programs to be called up manually should be assigned to the user-definable function keys. This is why preference should be given to desk calculators having many and conveniently arranged function keys of this type. Function keys initiating an unconditional jump to a label are preferable. This is different, for example, in the HP-9810 model where a separate subroutine is opened in response to every call. However, subroutine nesting is limited to only a few levels (e.g. to 5).

4.7 Degree of interactivity

The development of a good interactive program requires both a profound knowledge of the programming language and great practical experience in the field of application, which in our case means in photogrammetry. Moreover, the programmer should have an intuitive understanding of the needs and problems of the operator who is to use the system to advantage. A well-designed interactive on-line program must make sufficient allowance for the actual measurement process within the overall system, for example, for the sequence of observations, the correction of measurement errors, access to and easy manipulation of generated files. A very high manual operating comfort is desirable, which is achievable by the formulation of clear and simple instructions to the operator. The interactive display and request should be logically adapted to the measurement and processing procedure in order to avoid mistakes to the largest possible extent. The program itself should interfere as little as possible with the actual work of the operator, namely stereo compilation and measurement.

Since the measurement process, the data processing and the making of decisions are heavily interrelated, an optimal interactive on-line program under given constraints will be the one which requests, processes or displays the proper data and information at precisely the right moment.

The display registers generally available in desk calculators serve to increase the degree of interactivity between man and machine. It is one of the primary tasks of on-line programming to make the best possible use of this feature. By suitable conventions, a flashing display may be given another meaning than a continuous one. Undoubtedly a display screen offers the highest information content at any given moment and is superior to any other display. On the other hand, a high degree of interactivity calls for a higher investment in program and storage capacity. Finding here a reasonable compromise may result in fundamental and principal decisions.

The human stereoplotter operator should not have to shift his attention from the actual measuring process. His primary task is the processing of optophysiological information in the stereoplotter. Calling computer programs should therefore be made neither with major changes of posture nor of visual adaptation. The frequent depression of buttons or keys on a calculator keyboard may eventually produce psychologically unfavorable marginal phenomena and thus considerably impair or even question the user-oriented quality of a system. Here instrument manufacturers will have to come up with completely new ways of integrating optical or optoelectronic components — preferably with digital control — into their equipment (human engineering). The "menu" approach being used successfully in digital cartography would undoubtedly be a first step towards "humanizing" computer-assisted stereoplotting systems (Freeman, 1975).

5. REQUIREMENTS OF DESK CALCULATORS

The considerations relevant to computer-assisted photogrammetric stereoplotting can be summarized in a list of requirements that will have to be made of an ideal type of desk calculators. However, these requirements are by no means absolute necessities; they are only made up of the items discussed in detail in chapter 4 (see Table I), being considered as essential by the author. There is no calculator that would satisfy each of the requirements listed in this table. Since many of the requirements are mutually exclusive, we can only aim at a compromise, i.e., we have to set priorities. The priorities assigned in Table I are best met by the desk calculator types WANG-720, HP-9810, HP-9815 and HP-9825; though this does not exclude other companies' computers.

TABLE I

Requirements made of desk calculators

Requirement	Priority	Reasons
3 display registers or alpha-numeric screen	2	Simultaneous display of 3 coordinates of a point. Instructions to operator.
1 magnetic cartridge with 2 tracks or 2 magnetic cartridges	1	Modular storage of program system. Separate storage of data.
User definable function keys (unconditional jump)	1	Depression of least possible number of keys for calling of program.
Built-in alphanumeric printer	2	Quasi-permanent data exchange and/or instructions to operator.
Arithmetic memory with at least 2500 commands. Data and program steps in the same memory	1	Accommodation of longer memory-resident programs. Higher flexibility.
Highest possible computing speed	1	Higher point density in dynamic recording
Very general programming language	3	Interchangeability
Simple editing of programs	1	Economical development and modification of programs.
Very generally conceived I/O-bus	3	Compatibility of control and data transmission of peripherals with different types of computer.

6. CASP PROGRAM SYSTEM

In cooperation with CARL ZEISS of Oberkochen, the modular CASP program system (Computer Assisted Stereo Plotting) was developed for a computer-assisted analog stereoplotting system. In its present form, the software is based on a Hewlett-Packard 9810A desk calculator with 111 data registers and 2036 instruction words, and either on the simple digital DIREC-1 interface (Schwebel, 1976a) or the computer version of the more sophisticated ECOMAT-12 control and recording unit (Schwebel, 1976b): CASP consists of a total of 5 program modules, three of which belong to the basic software (STATRECORD, LISTMANIPUL, DYNRECORD) and two to the application software (ABSOLOR-1, ABSOLOR-2). Each of the different modules is permanently stored on a 6-inch magnetic card and includes various operating, realtime and user programs. Table II lists the different keyboard programs with brief explanations. Most of these routines are called from the calculator

TABLE II

Definitions of keyboard programs in CASP program system

Module 1: STATRECORD — Recording of points with real-time transformation	
CONCO	Real-time display of counter coordinates
MODCO	Real-time display of model coordinates
TERCO	Real-time display of ground coordinates
TECCO	Real-time display of ground coordinates with correction for earth curvature
RTAREA	Real-time computation of areas
RESET	Resetting of data storage to initial state
DFPAR	Definition of real-time transformation parameters
DFECC	Definition of earth-curvature correction
SAVE	Saving of instantaneous state of data storage
POINT*	Generation and input of point numbers
AVERAGE*	Averaging of multiple measurement with error display
STORE*	Storage of measured points in a model control-point list
CANCEL*	Cancellation of points just recorded or stored
RECORD*	Recording of points
THRULIST	Inspection or modification of model control-point list
CNTRLIST	Inspection or modification of ground control-point list
Module 2: LISTMANIPUL — Checking, inspection and modification of control-point lists	
THRULIST	Forward location, inspection and/or modification of model control-point list
CNTRLIST	Inspection and/or modification of ground control-point list
BACKLIST	Backward location of model control-point list
DELETE	Erasure of a list point
INSERT	Addition of a point to the control-point lists
TRANSFER	Transfer of interface coordinates to model-control-point list
REDUCE	Reduction of control-point type
EXTEND	Extension of control-point type
PRTLIST	Printing of control-point list(s)

keyboard, a few more frequently used ones from the keyboard of the DIREC-1 or the ECOMAT-12 (in Table II, DIREC-1 marked by an asterisk). Fig. 2 gives the layout of a CASP template intended for the user, as designed for a system with DIREC-1. Fig. 3 represents a block diagram of the overall program system with its normal flow of information.

The essential point of the two modules STATRECORD and DYNRECORD is the concept of a real-time program serving for so-called real-time display and/or real-time processing of transformed "counter coordinates" supplied by DIREC-1 or ECOMAT-12. The calculator is "informationally" connected to the opto-mechanical stereoplotter via this essential part of the program, the two thus becoming a single measuring unit as soon as the real-time program is in progress. The real-time program cyclically acquires the counter coordinates, transforms them into specially defined model or ground coordinates and either briefly puts the transformed data into the display registers in the case of point measurement or immediately stores them in an external medium

TABLE II (continued)

Module 3: DYNRECORD — Recording continuous lines with real-time transformation	
CONCO	Real-time display of counter coordinates
MODCO	Real-time display of model coordinates
TERCO	Real-time display of ground coordinates
TECCO	Real-time display of ground coordinates with correction for earth curvature
RESET	Resetting of data storage to initial state
DFECC	Definition of earth-curvature correction
SAVE	Saving of instantaneous state of data storage
RCMOD	Selection of recording mode by intervals of time, travel or coordinates, or manual
POINT*	Generation and input of point numbers
FEATURE*	Generation and input of feature code
SPFEAT(1)*	Generation and input of special feature code
SPFEAT(2)*	Generation and input of special feature code
SPFEAT(3)*	Generation and input of special feature code
RECORD*	Recording of points or lines
Module 4: ABSOLOR-1 — Absolute orientation with transformation parameters	
INIT	Determination of approximate values of some transformation parameters
ABSOR1	Computation of parameters of a spatial Helmert transformation
RESID	Computation and output of residual coordinate errors of control points
PRTPAR	Output of transformation parameters
CALLSTAT	Call STATRECORD and take over relevant data
Module 5: ABSOLOR-2 — Absolute orientation with setting parameters	
ABSOR2	Computation of setting parameters for stereoplotter
CARRY*	Acknowledge set parameters
CALLSTAT	Call STATRECORD and take over relevant data
CALLDYN	Call DYNRECORD and take over relevant data

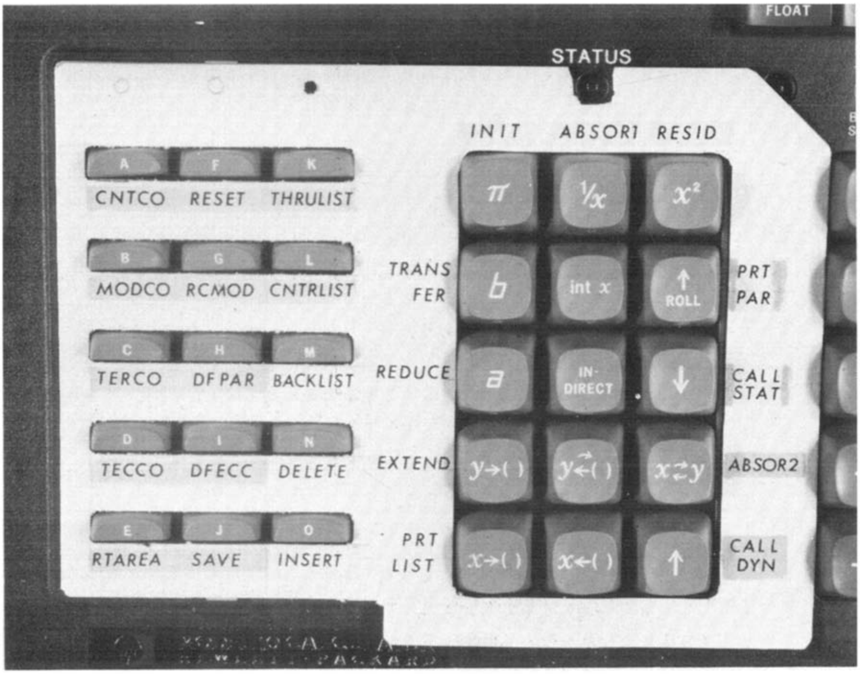

Fig. 2. CASP-template for the HP-9810A computer.

in the case of continuous line plotting. The underlying consideration is to use real-time display to signalize to the user that the system is ready for actual measurement in the stereoplotter.

Most of the other programs are grouped around the real-time program as a central unit. During the coordinate input controlled by this basic program, the operator can observe the coordinates on the display; he can set certain data in real time by changing the model points defined by the pair of measuring marks; he can switch from counter to model or ground coordinates (CONCO; MODCO; TERCO; TECCO); he can define and generate point numbers (POINT) and measure model points once or several times as well as read, store (STORE), record (RECORD) and/or average (AVERAGE) the corresponding coordinates. Or he can define (FEATURE, SPFEAT (i)) linear features with the aid of a feature code and record them (RECORD).

As is evident from Table II, the routines to be activated via the keyboard of the DIREC-1 of ECOMAT-12 are needed very often. In view of the special type of data transfer between HP-9810 and DIREC-1 or ECOMAT-12 (Schwebel, 1976b), these programs can be activated by a single key depression only if the real-time program is in progress. It is up to the programmer to avoid undesirable operating errors by limiting the interrogation of keyboard codes (Schwebel, 1976b) at a given moment.

The most essential relationships governing static and dynamic recording have

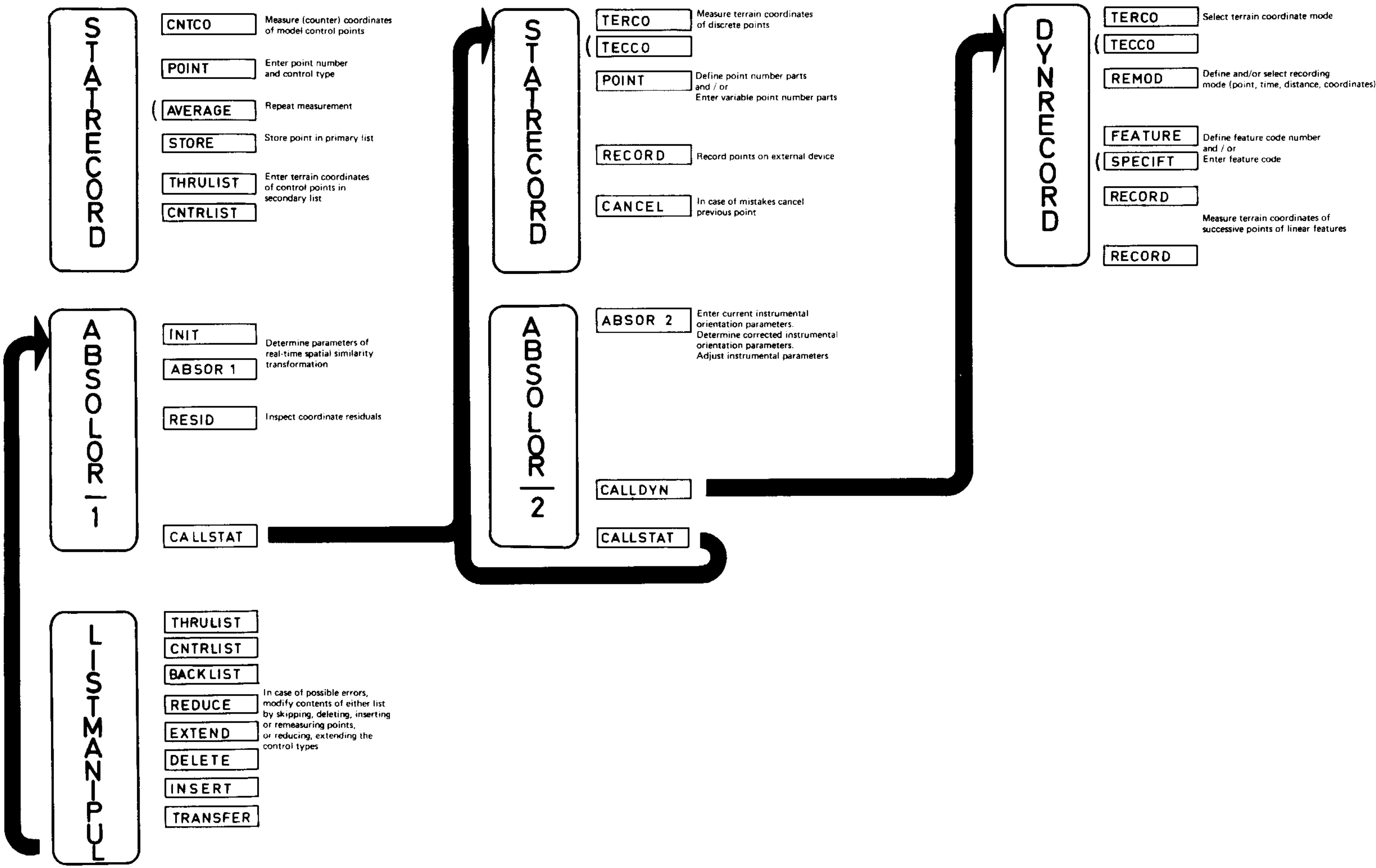

Fig. 3. Block diagram of the Computer-Assisted Stereo Plotting system (CASP).

been described in detail in Dorrer (1976). Within the 10 display digits available in the calculator, CASP allows practically any arrangement of constant, serial and variable components of a point number (POINT) or a feature code (FEATURE) to be defined. Continuous incrementing of point or feature numbers is guaranteed in a flexible manner just as the possibility of erasing a point just measured (CANCEL), or that of simultaneous recording and storage of a point. In the case of point measurement, the foot control (RECORD) is equivalent to a key; in the case of continuous measurement it functions as a switch.

STORE allows the coordinates and point numbers of a maximum of 11 points of a list to be put into the calculator's memory. This is of importance to the preparations for absolute orientation. The THRULIST routine allows checking and, if necessary, modification of the list contents, while CNTRLIST controls the input of ground control coordinates into a second list homologous with the first. A maximum of eight control points can then be stored in the two lists simultaneously.

The continuous recording of linear features is made possible by several alternative real-time routines characterized by a so-called recording mode (RCMOD). Four modes are available, viz., recording by intervals of time (1), intervals of distance (2), coordinate intervals (3) and manually (0). In the time mode, counter coordinates can be recorded at a maximum 0.08 s, ground coordinates at 0.16 s, if the speed of the recording unit is neglected. In the distance mode, real-time interpolation to the fixed interval of distance is required in view of the relatively low computing speed. The same applies to the coordinate mode: the recording covers coordinates interpolated to the spatial grid previously defined by RCMOD. The manual mode is required above all for man-made objects such as buildings, but also for cases in which maximum accuracy is needed. During dynamic recording, a list of feature codes is automatically generated, different objects of the same kind being distinguished by incrementing code components.

The LISTMANIPUL module serves for the interactive manipulation or modification of the two control lists. Especially if inexplicable errors are encountered during absolute orientation, LISTMANIPUL will be very valuable for an immediate clarification and, if necessary, correction of the corresponding error in the initial or measurement material. The various data editing functions of this module are shown in Table II and Fig. 3. Special attention was here given to a high degree of interactivity and a logical concept.

The application software gives an interactive and rigorous solution of absolute orientation. It consists of two modules.

The ABSOLOR-1 module is equivalent to an equipment-invariant first phase of numerical orientation. Via a rigorous least-squares adjustment, it computes the seven parameters of a spatial similarity transformation from the two stored sets of control points, the counter coordinates measured and the entered ground coordinates, plus the residual errors of the control points, if so desired. The stochastic model is based on the assumption of erroneous, equally weighted ground coordinates, as this form directly yields the parametric adjustment case and thus appears particularly well suited for desk calculators. Vertical, horizontal and fully spatial control points may be used. This is very often of decisive importance for practical work. In CASP the control type is defined by an additional digit within the point number: 3 for spatial, 2 for horizontal and 1 for vertical control points.

The transformation parameters are determined by an iterative procedure. Approximate values are required only for the four Euler parameters of the (scaled) rotation matrix. INIT (see Table II or Fig. 3) serves to compute the scalar factor between the counter and ground coordinates as well as the azimuthal rotation. The program can handle any azimuth, but requires the two coordinate systems to follow the same orientation. The method normally converges already after the third iteration, the standard error of unit weight and the test parameter to be compared with a convergence parameter (10^{-8}) being printed out after every step. One iteration step takes about 15 s. The program stops as soon as convergence has been attained. The transformation parameters computed are immediately available for real-time transformation of counter into ground coordinates (STATRECORD and DYNRECORD modules).

If the residual errors printed out after adjustment by means of RESID do not live up to expectations, ABSOLOR-1 can be repeated as often as is desired after suitable modification of the control lists by LISTMANIPUL. It is precisely this interactive trouble-shooting and detection "in situ" which is one of the most valuable advantages of computer-assisted stereoplotting.

If the actual, physical stereomodel is to be oriented absolutely, e.g. for the direct digitization of contour lines, phase 2 of absolute orientation (module ABSOLOR-2) is required. While phase 1 is completely sufficient for point measurement, it is inadequate for the measurement of lines, referred to the vertical. On the basis of mathematically rigorous formulations, ABSOLOR-2 computes the setting elements required for an optimal absolute orientation of the stereomodel. Required are the transformation parameters transferred from ABSOLOR-1 and the current instrumental parameters for the base and the projector tilts. The corresponding values of these elements have to be manually transferred to the stereoplotter by the operator. ABSOLOR-2 modifies automatically the real-time transformation parameters determined during phase 1. This guarantees that the physical orientation of the instrument agrees with the digital orientation determined by the calculator.

If after absolute orientation, the operator agrees with the parallax and height conditions in the stereo model, he can call CALLSTAT or CALLDYN to request the recording module STATRECORD or DYNRECORD and start recording the ground-referenced data.

The mathematical formulation of the ABSOLOR-2 program module is based on the spatial design of a stereoplotter of the PLANIMAT or PLANICART type. It is a special characteristic of these instruments that the gimbal axes of projector tilt are eccentrically arranged with respect to the corresponding perspective centers. Also, transverse tilt defines the primary, longitudinal tilt the secondary rotation. The program is therefore applicable to basically all stereoplotters using the same arrangement of axes, even if the tilt axes are centrical. If ΔR denotes the orthogonal matrix responsible for rotating both the base vector b and the two projectors already oriented by their tilt matrices T_1, T_2 respectively, if $\Delta\lambda$ is the factor the stereomodel has to be scaled with, and if the vector a defines the eccentricity of the tilt axes, the setting elements are then given by the following expressions:

$$b^1 = \Delta\lambda\Delta R \cdot b + (\Delta\lambda - 1\ \Delta R \cdot (T_2 - T_1) \cdot a$$

$$T'_1 = \Delta R \cdot T_1$$

$$T'_2 = \Delta R \cdot T_2$$

The clockwise rotations are defined in a mathematical Cartesian system. Conversions to instruments of different senses of rotation are of trivial nature only.

ABSOLOR-2 makes ample use of the printer incorporated in the calculator, which prints out all instructions to the operator. Practical test examples have shown that most of the operator's time is taken up by reading and setting the orientation elements. If there are no complications, phase 2 requires a maximum of two minutes. In view of the rigorous adjustment in phase 1 and the mathematically rigorous formulas in phase 2, both an increase in accuracy and a considerable saving of time can be expected by comparison with purely empirical absolute orientation. The CASP program system therefore represents another step towards an economic solution for acquisition and orientation of photogrammetric data.

7. OUTLOOK

On the level of desk-top computers, the development of interactive computer programs for the purpose of computer-assisted photogrammetry very soon reaches the limits of the available hardware and of economical justification as far as software is concerned. Concerning expenditures, the software costs are of the same order of magnitude as those involved in procuring the necessary hardware: a frequently overlooked fact. Consequently, the efforts of computer manufacturers directed towards the development of efficient, easily understood, generally accepted and problem-oriented dialog languages that can also be used in conjunction with small computers are to be strongly supported. The APL language developed by IBM (Iverson, 1972) is the most promising development in this respect (see also Fig. 4). In the hardware field, the general trend is towards small computers (microprocessors) and hardwired programs via ROMs, PROMs and RAMs (firmware) that are primarily used for control purposes. Here again, photogrammetric instrument manufacturers will find a wide field of opportunities.

BASIC	APL
see code below	`X[⍋X←⎕]`

BASIC

```
10 DIM X(100),Y(100)
20 READ N
30 FOR I=1 TO N
40 READ X(I)
50 NEXT I
60 FOR I=1 TO N
70 LET A=X(I)
80 LET L=1
90 FOR J=1 TO N
100 IF A<=X(J) THEN 130
110 LET A=X(J)
120 LET L=J
130 NEXT J
140 LET Y(I)=A
150 LET X(L)=100000
160 PRINT Y(I)
170 NEXT I
180 DATA
    - - - -
    - - - -
    - - - -
XXX END
```

APL

```
X[⍋X←⎕]
```

Fig. 4. Program comparison of BASIC and APL dialog languages for an ordinary problem concerning sorting of a series of numbers.

REFERENCES

Berger, F., Frey, U. and Kreuzer, J., 1974. A new photogrammetric data acquisition system: the Wild EK22. Paper presented at the 14th F.I.G. Congress, Washington, D.C., 1974.

Dorrer, E., 1976. Rechnergestützte Stereoauswertung — Aufgaben, Rechenprogram, Erfahrungen. Mitt. Inst. Photogramm. Tech. Univ. Stuttgart, No. 2. (Lecture given at the 35th Photogrammetric Week 1975).

Dorrer, E. and Kurz, B., 1973. Plotter interfaced with a calculator. Photogramm. Eng., 39: 1065—1076.

Dorrer, E., Lander, E. and Toraskar, K.V., 1974. From analog to hybrid stereoplotter. Photogramm. Eng., 40: 271—280.

Freeman, C., 1975. 9830A System Speeds pipeline measurement. Hewlett-Packard Keyboard, 7(5): 8—9.

Harley, I.A., 1971. An exact procedure for numerical orientation of a plotting instrument. Photogramm. Rec., 7 (37): 27—38.

Helava, U.V., 1958. Analytical plotter in photogrammetric production line. Photogramm. Eng. (Dec. 1958).

Hofmann, O., 1961. Das Coordimeter: Ein programmierbarer Leser und Rechner für photogrammetrische Auswertegeräte. Kompendium Photogrammetrie, IV. Jena, pp. 26—51.

Iverson, K.E., 1972. A Programming Language. Wiley, New York, N.Y.

Jeyapalan, K., 1974. Applications of programmable desk calculators in photogrammetry. Proceeding of the 40th Annual ASP Meeting, St. Louis, March 10—15, 1974.

Keene, M.L., 1974. Model setting by computer. Proceedings of the 40th Annual ASP Meeting, St. Louis, March 10—15, 1974.

Kröll, F.S., 1974. Digitale Erfassung topografischer Daten und deren automatische Verarbeitung. Bildmessung Luftbildwesen, 1974(3): 87—93.

Schwebel, R., 1976a. Rechnergestützte Stereoauswertung — Instrumentelle Möglichkeiten und Voraussetzungen. Mitt. Inst. Photogramm. Tech. Univ. Stuttgart, No. 2. (Lecture given at the 35th Photogrammetric Week 1975).
Schwebel, R., 1976b. Das neue photogrammetrische Datenerfassungs- und Übertragungssystem ECOMAT 12. Paper presented at the 13th International Congress for Photogrammetry, Helsinki, 1976.
Tsivos, V.A. and Dorrer, E., 1975. On-line instrument testing and operation procedures. Proceedings 41st Annual ASP Meeting, Washington, D.C., March 9—14.
Wood, R., 1974. The application of the programmable calculator to numerical orientation. Photogrammetric Rec., 8 (43): 101—106.
Wood, K.B., Gross, S.B. and McPherson, C.H., 1974. Automation with the Wild A10 plotter. Proceedings 40th Annual Meeting, St. Louis, March 10—15, 1974.