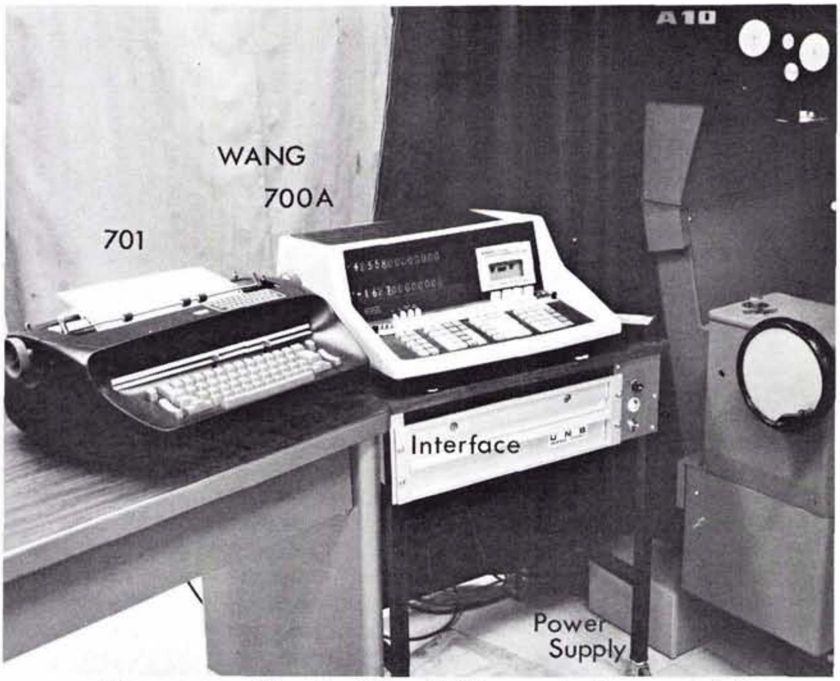

FRONTISPIECE. Here the Wang-DRC computer is connected to the Wild A-10 stereoplotter.

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Plotter Interfaced with a Calculator

Interfacing a programmable desk calculator directly with a stereoplotter results in a variety of interesting and usable features.

INTRODUCTION

PHOTOGRAMMETRIC computations are presently accomplished mostly off-line on large electronic data processing systems. This fact entails very often a considerable time lapse between the actual measurement and the analysis of the observational data. The total photogrammetric data processing complex, however, can be subdivided into a number of steps of different procedures or tasks. Many procedures, particularly during the actual mensuration stage, could be performed more conveniently and more reliably with the help of a small digital computer. This is particularly true for instant result requirements. In addition, rough data often need to be edited or refined before they are entered into a larger processing system.

ABSTRACT: *Design considerations and test applications of an on-line operated Wang 700 desk calculator interfaced with a Wild A-10 stereoplotter are discussed. Utilizing the input/output connector of the calculator, a special electronic interface using integrated TTL-circuits was built. Three separate up-down counters accept either square-wave or pulse output from three incremental shaft encoders. Strobed into a buffer in parallel, the pulse counts are read digitwise into the calculator. The input process can be initiated from either the keyboard manually or under program control periodically. The modular arrangement features data acquisition speeds up to 60 spatial model points per second, flexible and simple programming and versatile output format. As a typical on-line data acquisition system it simultaneously can digitize, store, display and process photogrammetric model coordinates and assist the operator in his decision-making capability. A variety of applications include on-line relative and absolute orientation, averaging repeated measurements and indicating current standard deviations, strip formation from independent models, correction for earth curvature, on-line computations and display of scaled or transformed model coordinates, distances, areas, or volumes. The ability to utilize the system as a programmable desk calculator when not in use for data acquisition makes it much more versatile and economically viable than a dedicated coordinate digitizer.*

Today, computer technology is capable of realizing numerical *on-line* photogrammetry in a surprisingly economic and reliable way. On-line in this context means the acquisition and processing of photogrammetric data right on the spot, i.e., practically simultaneously with the restitution, mensuration or compilation of photographs. The purpose of this paper is to describe both hardware and software features of a simple inexpensive and economic modular photogrammetric on-line data acquisition system, consisting of a WANG Model 700A programmable desk calculator and a WILD A-10 stereoplotter. The study was conducted at the Department of Surveying Engineering, University of New Brunswick, Canada.

THE BASIC IDEA

Basically, an inexpensive but effective method was to be implemented by which discrete photogrammetric stereoplotter data could be digitized, processed and eventually analyzed during the process of restitution. Many problems in computational photogrammetry are of such a nature as not to justify the use of larger computers. Instead, the results are required instantly, the experiment must be repeatable if necessary immediately, operator decisions are to be facilitated by means of on-the-spot processed data, etc.

Probably the first such open-loop photogrammetric system was the Zeiss-Jena relais computer COORDIMETER[1] in conjunction with a Stereometrograph. Later a truly electronic design, the CELLARTRON[4], was offered. However, such special-purpose computers cannot be justified anymore from an economic point of view. General-purpose computers are much more efficient, being capable of any kind of calculations, easier programming, benefitting from a better service, and are less expensive.

The conventional digitization of photogrammetric data is accomplished with dedicated coordinate digitizers, data loggers or quantizers. These electronic hardware devices receive shaped sine waves or pulses from optical shaft-angle encoders attached to the *X*-, *Y*- and *Z*-spindles of a stereoplotter. The pulses are counted, refined, displayed (e.g., on Nixie-tubes) and made available for other equipment such as hardcopy output writer, paper tape puncher, card puncher, magnetic tape. Digitizers are manufactured by various companies; examples are the WILD EK-8, DATA-TECH, WANG 2300, DELL FOSTER RSS 400, KERN ER1. Depending on the features included, prices lie in the range between \$5,000 and \$15,000. These devices fulfill an urgent need, viz., to supply digitized analog photogrammetric data to a large data processing system. They are, however, rather inflexible as far as data formatting, scaling, or processing is concerned. Dedicated hardware scalers are offered to introduce different scales, dedicated digital planimeters are offered to determine areas, and more or less sophisticated wiring manipulations are needed to change the output file format.

As will be obvious in one of the following sections, by interfacing a control computer directly with the output from the shaft angle encoders, data not only can be digitized in a similar way as with a dedicated digitizer, but the data can also be further processed by the computer on-line and in real-time. The processing is completely controlled by computer software, and is therefore extremely flexible and versatile.

The choice between a minicomputer and a programmable desk calculator was made in favor to the desk computer. The reasons are that the desk-top calculator, due to its dedication, is a more personal, interactive computing tool, its keyboard programming language is extremely simple, it works directly with decimal numbers, and it costs less than most of the existing minicomputers. Among several desk computers, the WANG Model 700 has been chosen because of its direct interfacing capability. All the other desk computers did not have this feature at the time a choice had to be made (1970). As of today, all major manufacturers are offering a wide variety of peripheral devices.

WANG MODEL 700A

The WANG 700 is a self-contained programmable electronic calculator constructed with integrated circuits on replaceable circuit modules. There are three basic elements:

- The *Central Processing Unit* (CPU), performs the arithmetic operations.
- The *Read-Only Memory* (ROM) guides the CPU, and is *the brains* of the system. It directs all arithmetic and logical operations and has been programmed to perform all the functions found on the 67 keys of the 700 keyboard.
- The *Core Memory* is organized into 122 data registers plus a nixie display of the two working registers *X* and *Y*. All user programs, including the trigonometric functions, are executed from core memory.

Programs or data can also be saved on standard 4 × 2.5 × 0.5-inch magnetic tape cassettes for later use.

The usefulness of the WANG 700 comes from its programming capabilities. A program is simply a logical sequence of steps which the calculator can perform automatically. The *keyboard* language used is similar to assembly languages on larger computers. Programs are loaded into core from the keyboard and executed from core. Features of the WANG programming language are direct and indirect addressing, the ability to perform arithmetic operations with all registers, to perform logical operations, to allow for two-nested subroutines, to load data or programs from tape into core automatically, to provide alphanumeric output for the 701 output typewriter, and to address optional peripheral equipment.

Each of the 122 storage registers has a 12-digit mantissa with sign and a 2-digit exponent with sign. The first 120 registers can be used for program storage, yielding maximally 960 program steps. All programmed operations are represented by a 4-digit code, consisting of two halves: a high-order 2-digit number and a low-order 2-digit number. Each of these halves can assume values between 00 and 15, thus providing a total of $16 \times 16 = 256$ codes.[6]

The input/output connector located in the rear of the Model 700 Series allows other external equipment to be interfaced directly to the WANG. Through this connector, data information can be received, program operations can be executed or program steps can be learned directly into the core memory. Specifications on the signals and signal functions, on the signal-to-pin correspondence of the I/O connector, on the input/output circuitry and the code format required for the interfacing are given in Reference 2.

Due to the word representation by a *high-order code* and a *low-order code*, the WANG 700 can directly accept binary-coded decimal (BCD) numbers from any external device.

To address the I/O connector, a two-step command (*GROUP1, XX* or *GROUP2, XX*) must be initiated from either the keyboard manually or from program control in core memory automatically. The *XX* portion of this two-step command designates the name of the peripheral device to be addressed. The group commands transfer control from the computer to the external device. After an I/O operation is completed, a *GO* command is required from the I/O input to return control back to the 700. The *GO* command returns control to the core memory if the initial *GROUP* command came from the program. In this instance, the program will continue at the next program step after the *GROUP, XX* command.

INTERFACE HARDWARE DESIGN

The stereoplotter selected was a WILD A-10 Autograph with EK-8 digitizer. For a preliminary study of the on-line data acquisition system, a small interface board was designed to allow EK-8 data to be received by the computer. It was possible with this unit to read a point number and three coordinate values with the same (slow) speed inherent to the EK-8 discrete point mode. Obviously, no significant gain could be expected from such a serial system. Therefore another interface was designed which could run in parallel, i.e., independent on the EK-8. This interface* should serve two independent functions:

- The signals supplied by the three incremental shaft angle encoders (in the following called digitizers) are preprocessed, and the resulting count pulses are counted by three separate 6-digit-plus-sign up/down counters.
- The interface controls the programmed data transfer of the counter contents into the WANG 700 computer.

If wanted, a real time numerical display (e.g., Nixie tubes) for monitoring the instantaneous contents of all three counters could easily be attached to the interface.

A general block diagram of the WANG-3DRC is shown in Figure 1. The logic can be subdivided into three functionally different units, viz.,

* Called: WANG-3DRC; i.e., Interface of WANG-700 with three *D*ynamics *R*esearch *C*orporation encoders.

★ The encoders for preprocessing the signals supplied by the digitizers,
★ The up/down-counters with their associated buffer, and
★ The data transfer logic.

The interface accepts signals from digitizers (here: incremental shaft-angle encoders) with or without built-in encoder logic. Square-wave signals supplied by shaft-angle digitizers without encoders showing a quadrature interchannel phase relation (as, for example, the DRC-77 built into the WILD A-10) are applied to the interface's two-count encoder to generate up-down count pulses corresponding to a clockwise/counterclockwise shaft rotation. For digitizers with built-in encoder logic, the encoders of the interface are bypassed. In this instance the count pulses from the digitizers are applied directly to the counter input terminals.

Each of the three counters consists of six up-down decades, providing a count capacity of six decimal digits plus sign information. The decimal counting system offers a handy means for data transfer of the counter contents into the WANG 700 computer, which accepts numbers sequentially in the form of coded decimal digits. A complete counter unit is shown in more detail in Figure 2. The

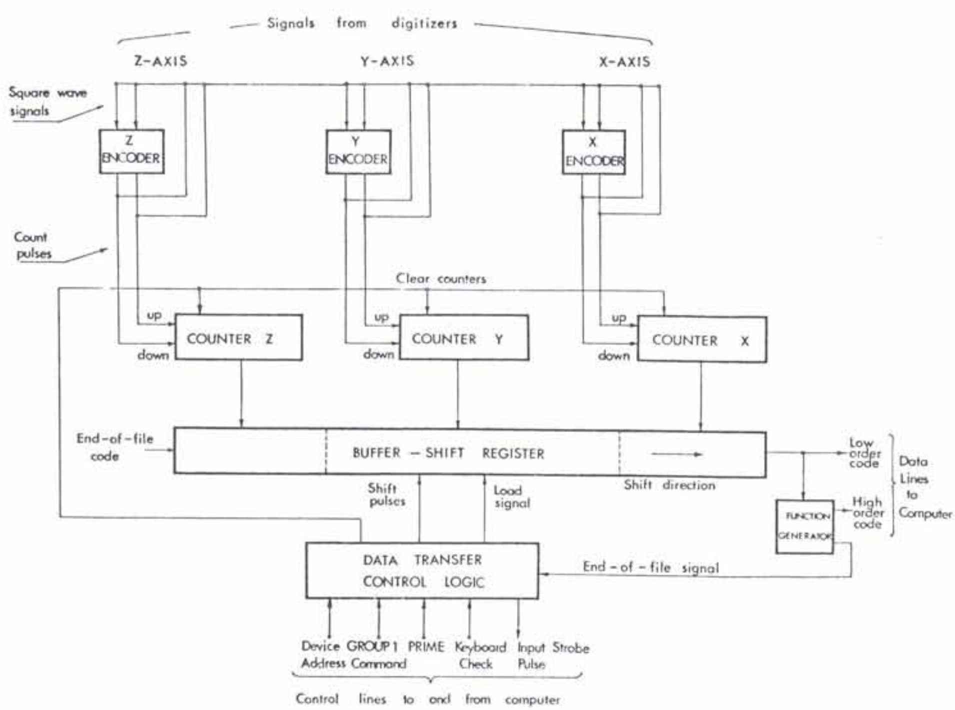

FIG. 1. General block diagram of Wang-3DRC interface.

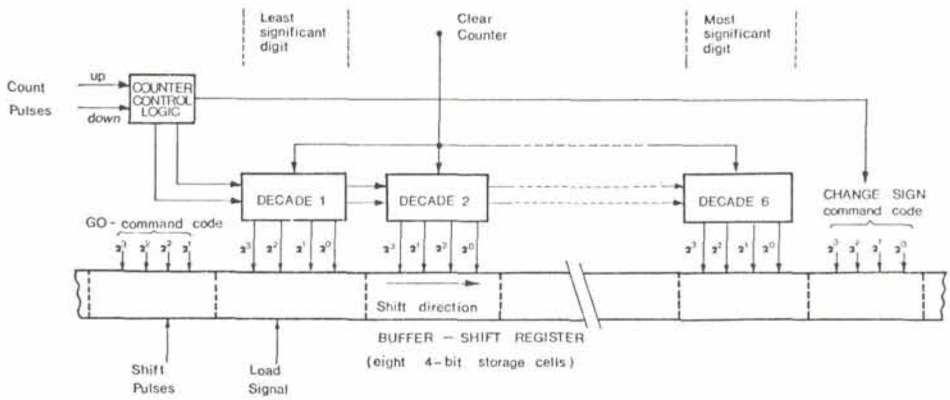

FIG. 2. Block diagram of one counter unit with associated buffer.

counter control logic in connection with the BCD-coded up/down decades allow for a true sign and magnitude representation of the counter contents; i.e., the sequence of numbers, while counting up, is, for example: −2, −1, 0, +1, +2, etc. The buffer is a multiple four-cell shift register associated with the counters, and it serves as temporary storage medium for the contents of all three counters and for additional information during a data transfer process. Upon applying a load signal to the buffer, the BCD-coded output information of all decades is strobed into the appropriate four-bit storage cells of the buffer along with the lower-order codes for the WANG 700 *GO*-command, as well as for the *CHANGE SIGN* command, provided a negative sign exists. For a positive sign, a decimal 0 replaces the latter.

The bit combination of the rightmost four-bit storage cells, closest to the data lines (see Figure 1), is externally accessible and represents the lower-order code of the current data word to be transferred via the data lines into the computer. In order to avoid another buffer-shift register for accommodating the higher-order codes of the complete data words, a function generator is used to generate the appropriate four bits of the higher-order code according to the current lower-order bit combination. This method is feasible due to the restricted use of only a few WANG code words including those for decimal digits and two commands.

The input process into the Model 700 is controlled and synchronized with the computer by means of the data transfer control logic. A flow diagram for the complete data transfer of x, y and z numbers is shown in Figure 3. A first *GROUP1* command, issued either by the program or manually from the keyboard, initiates the input process. Upon this data request the contents of all three counters are strobed simultaneously into the buffer without interrupting the counting process. They are retained there during the data transfer period. The input process of the stored counter contents is performed in the sequence x, y, z. Each number is read digit by digit into the Model 700 computer, led by the sign information and terminated by a *GO*-command. The sign information represents a *CHANGE SIGN* command for a negative number, whereas a decimal 0 occurs for a positive one. In the second application the leading zero is insignificant and will be suppressed by the WANG computer. The transfer of each single data word is initiated by an input strobe pulse and its completion is indicated by the returning keyboard check indicator signal *GKBD*. After occurance of the latter the entire buffer contents is shifted towards the data line terminal until the next data word is supplied on the data lines. A *GO*-command, issued by the interface concludes the data transfer of each number and causes control to remain with the WANG computer.

Three *GROUP1* data requests are needed to read the sign-magnitude information of the x, y, z counters into the computer, performed within a program loop as shown in the flow diagram in Figure 3. For moving the entire buffer contents towards the data lines, an end-of-file code (EOF) is shifted through the buffer. This code appears at the data line terminal after the *GO*-command for the z counter has been issued, thus signalling the end of a complete data transfer event to the data transfer logic.

A *GROUP1* instruction represents a two-step command, the first key stroke indicating

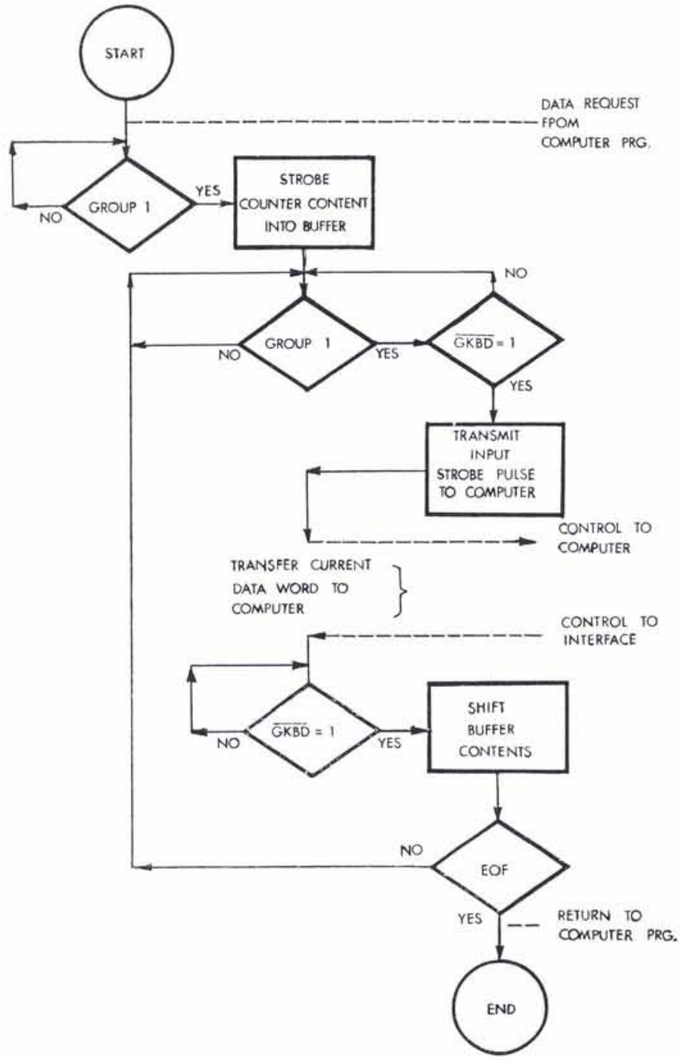

FIG. 3. Interface flow diagram of data transfer into Wang 700 computer.

data request, the second one specifying the external device address. *CLRX* used as device address will reset all counters to zero. The master reset key *PRIME* is utilized by the WANG-3DRC interface resulting in resetting the control logic of the interface, however, without affecting its contents.

The Frontispiece shows the WANG-3DRC connected to a WILD A-10.

SOFTWARE DEVELOPMENT

A simple photogrammetric on-line data acquisition system such as described previously can be used for digitization, processing and analysis of data. Digitization itself can be controlled by a unit specially designed for this purpose, or by a digital computer. In the latter instance, the digitizing system is more flexible because alterations and additions, in order to meet different applications, are accomplished on the software rather than the hardware. Immediate processing of the digitized data, however, is made possible only by a computer on-line. In a recent report, Masry[3] discussed various computer-controlled real-time systems. Where his concern lies mainly on the level of the analytical stereoplotter, the present paper attempts to show the usefulness and ease of operation of the simplest class of on-line systems.

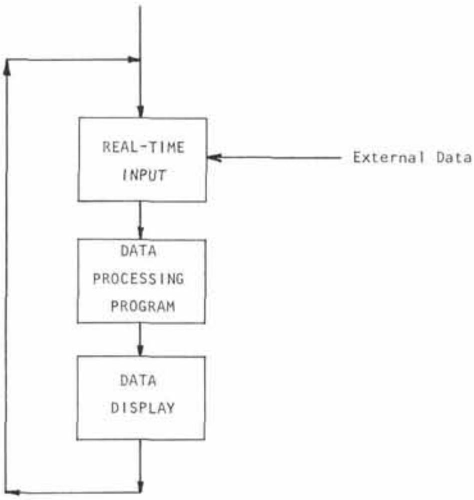

FIG. 4. Basic arrangement of a real-time program for the Wang-3DRC.

DIGITIZATION

Due to its two display *X* and *Y* registers, the WANG can be used for real-time display monitoring of model coordinates (Figure 4). This is possible because a certain *PAUSE* command allows the *X* and *Y* registers to be displayed for 0.5 seconds at any predetermined point within a program. The simultaneous displaying of two model coordinates only can be considered as a disadvantage, but it has been found that very rarely all three coordinates should be visible at a time. The user can make his own straight-forward real-time display programs, such as *XY*-display, or *Z*-display, or any other combination of one or two coordinates. Also rotational real-time display programs can be written.

The program in Table 1 is an example for a real-time *XY*-display; i.e., only the first two buffer contents are relevant. Real-time programs usually are initiated manually from the keyboard by depressing the appropriate function keys. As can be seen also from the Frontispiece, such a program usually cannot stop by itself, but has to be interrupted from the keyboard. By continuously activating the handwheels and the footwheel of the stereoplotter, the operator can read in real-time (to be more precise, after a minimum delay time of 0.5 seconds) the model coordinates as long as the interface unit is switched on.

In the particular program example, one register besides the two working registers is required for temporary storage of the *X* coordinate. The *Z* coordinate, after having been read into the computer, because not required here, is simply overwritten by the *X* coordinate. Several sequential *PAUSE* commands could be used for execution delays longer than 0.5 seconds. It is important to read the three model-coordinates one after the other as quickly as possible in order to assure affiliation to the same model point, particularly in the continuous mode of measurement.

As it stands, this real-time routine would display the *X* and *Y* model coordinates in units of pulse counts defined by the logic of the shaft angle encoders. It is, however, very

TABLE 1. SIMPLE REAL-TIME INPUT PROGRAM

	(X)	*(Y)*	*COMMENTS*
MARK			
RTXLDISPL			Real-Time XY Display
CLX	O		Clear X Register
GROUP 1			Read Buffer Contents
1	X		Into X-Register: (X) ← X
STDX			Store Directly Contents
001			Of X-Register into Register 001
CLX	O		Clear X-Register
GROUP 1			Read Buffer Contents
1	Y		Into X-Register: (X) ← Y
↑		Y	(Y) ← Y
GROUP 1			Read Buffer Contents into
1	Z		X-Register: (X) ← Z
REDX			Recall Directly Contents of
001	X		Register 001 to X Register
PAUSE			Halt Program for
UNIT	X	Y	0.5 Seconds
SEARCH			Repeat Routine
RTXYDISPL			

easy to multiply the coordinates with any desired factor within the number range of the WANG 700 prior to displaying them. The real-time program would be only slightly longer. This example shows the advantage over dedicated hardware scalers as being offered by a few companies.

If switched off, the interface unit loses its buffer contents. This is easily seen after switching it on again; the new buffer contents are purely random and show no correlation to the values prior to turning off the power. In order to be able to keep at all times an exact spatial connection between stereomodel and real-time program, provisions must be made to save the buffer contents in the computer memory before power turn-off and to restore the previous connection after power turn-on. A real-time program somewhat modified from the one shown, can do that in conjunction with two smaller routines. A program denoted by *SAVE* stores the current real-time model coordinates in three locations and saves them. It is assumed that the stereoplotter is not touched after power shut-off. The system can be restarted by initiating a program called *RESET;* it sets all three buffer contents to zero and jumps automatically to the same previously used real-time program. Although the latter feature is not really necessary, it nevertheless helps the operator, who should concentrate on the stereoplotter measurement rather than on keyboard manipulations.

Digitizing of planimetric detail or contours requires different modes of recording the coordinates, *viz.*, point mode, time mode and distance mode of recording. All three modes can be programmed on the WANG-3DRC. In point mode, the currently executing real-time program has to be interrupted by the operator manually by depressing either of the keys *PRIME* or *STEP*. After entering a point identification number into *X* register, another routine can be initiated for instance to store the number in a location prior to the *X* coordinate, or to prepare it together with the model coordinates for manual recording on magnetic tape cassette. This routine could have as its last instruction a jump back to the original real-time program, thus releasing the operator from another keyboard operation.

Both time and distance mode of recording are used for continuous digitizing of lines, mostly contours. The *PAUSE* command of the WANG enables time intervals to be set in multiples of 0.5 seconds. Another way would be to execute a dummy loop a large and preselectable number of times within the main program. In the distance mode recording occurs only if the accumulated displacement of the floating mark is equal to or has exceeded a certain value. The value of the distance can be selected by the operator. Principally, a program similar to the one shown in Figure 5, which computes the length of a traced curve, is used for distance determination. No real-time coordinate display should be exercised in this case, as any detail between consecutive 0.5-second displays are omitted. The present on-line system without a fast programmable recording capability, however, cannot make use of the advantages of a continuous mode digitization, the core memory being not large enough to hold all the incoming data.

Maximum input rate to the WANG Model 700 is 600 microseconds between adjacent digits, equivalent to 1600 characters per

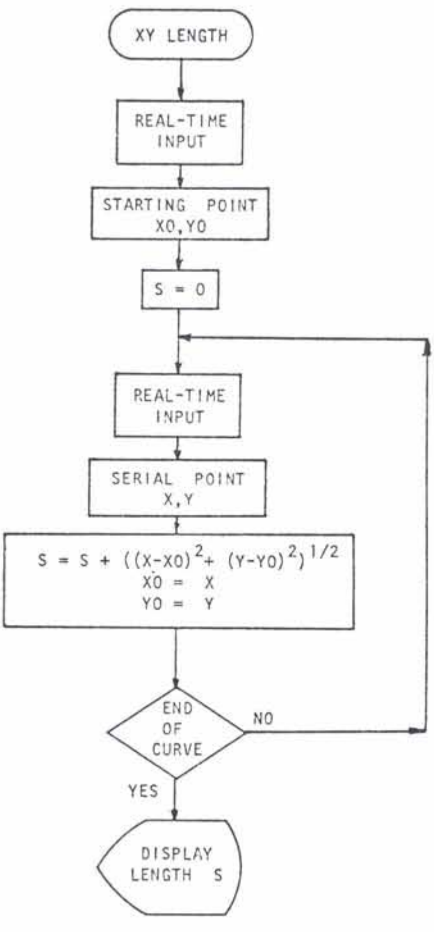

FIG. 5. Wang-700: Length of a curve.

TABLE 2. APPLICATION OF THE ON-LINE DATA ACQUISITION SYSTEM STEREOPLOTTER–WANG 700 DESK CALCULATOR

PARTICULAR APPLICATION	*COMMENTS*
Height correction for earth curvature	
Scaling of coordinates	Metric to English system
	Change gears obsolete.
Averaging repeated measurements	Sequential standard errors
Digital planimeter	Areas, cross-sections, profiles
Volume computations	Highway cut and fill
	Open pit mines
Coordinate transformation	E.g. real-time display of ground coordinates
Relative and absolute orientation	Semi-automatic
Perspective center determination	Grid measurements
	Intersection, resection
Strip formation from independent models	Recording of coordinates on magnetic tape
Strip adjustment	
Automatic coordinate recording in intervals of time or distance	

second. As each coordinate is composed of a six-digit number plus sign and termination command, highest possible transfer rate is 60 model points per second from the stereoplotter into the computer memory. This speed is more than sufficient for the WANG calculator.

DATA PROCESSING

The main advantage of a computer-con-

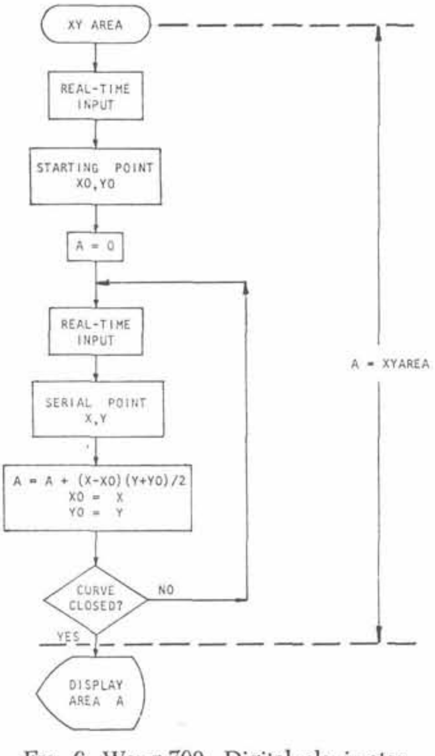

FIG. 6. Wang-700: Digital planimeter.

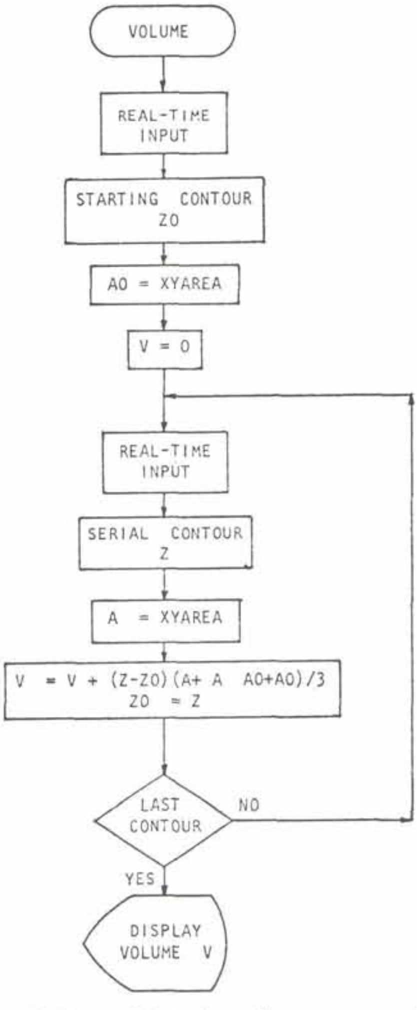

FIG. 7. Wang-700: Volume by contour sections.

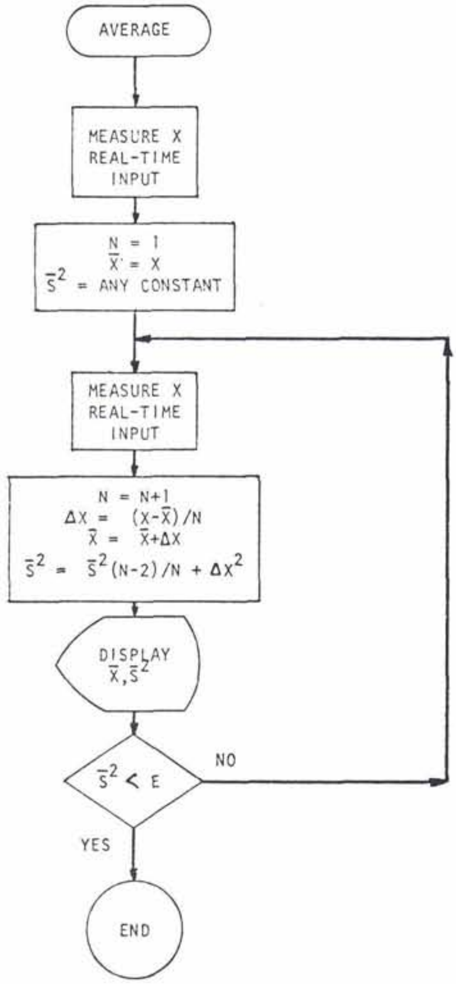

FIG. 8. Wang-700: Sequential average of multiple observations of a random variable X.

trolled on-line system lies in its ability to perform virtually any logical or arithmetic operation on the data picked up from the external device. Table 2 illustrates a number of potential applications of the system. More detail is indicated in the Figures 6, 7 and 8. Figure 6 shows a flow chart of a digital planimeter program. Without having to use a special hardware feature, this program permits the determination of the horizontal area of a closed curve followed by the measuring mark. A more complicated program for the determination of the volume of an object is shown in Figure 7. The object has to be scanned along contour lines separated by any chosen contour interval. Each two adjacent closed contours, the areas of which are determined as in Figure 6, contribute to the total volume. The individual contributions are accummulated until the operator has decided to stop. A completely different problem is tackled in Figure 8, *viz.*, the sequential averaging of multiple observations. Each time a model point is remeasured, a weighted mean between all previous measurements and the new measurement is computed as well as the standard deviation of the new mean. Both values are displayed for the operator to decide whether another measurement is required or not.

Relative and absolute orientations of stereomodels are faciltiated by an on-line system, but only absolute orientation may be justified economically. A possible operational procedure is shown in Table 3. The operator, after having entered ground-control coordinates and exterior-orientation parameters as they resulted from relative orientation, has only to measure the model coordinates of

TABLE 3. ABSOLUTE ORIENTATION. WANG-700. OPERATIONAL PROCEDURE

(1) ENTER	° Ground coordinates of control points (X_i, Y_i, Z_i). ° Exterior orientation parameters $\alpha' = (\omega', \Phi', \kappa')^T \quad B' = (BX', BY', BZ')^T$ $\alpha'' = (\omega'', \Phi'', \kappa'')^T \quad B'' = (BX'', BY'', BZ'')^T$.
(2) CALCULATE	° Orientation matrices and base components $R'^{\circ} = R(\alpha') \quad R''^{\circ} = R(\alpha'') \quad B^{\circ} = B'' - B'$.
(3) MEASURE	° Model coordinates of control points $(X_i^{\circ}, Y_i^{\circ}, Z_i^{\circ})$.
(4) CALCULATE	° Parameters of similarity transformation (C, λ, A) by sequential least squares adjustment. ° Rotated base components $B = A\ B^{\circ}$ ° Rotated orientation matrices $R' = A\ R'^{\circ} \quad R'' = A\ R''^{\circ}$ ° New orientation angles $\alpha' = \alpha(R') \quad \alpha'' = \alpha(R'')$.
(5) SET	° Orientation parameters in stereoplotter dials.

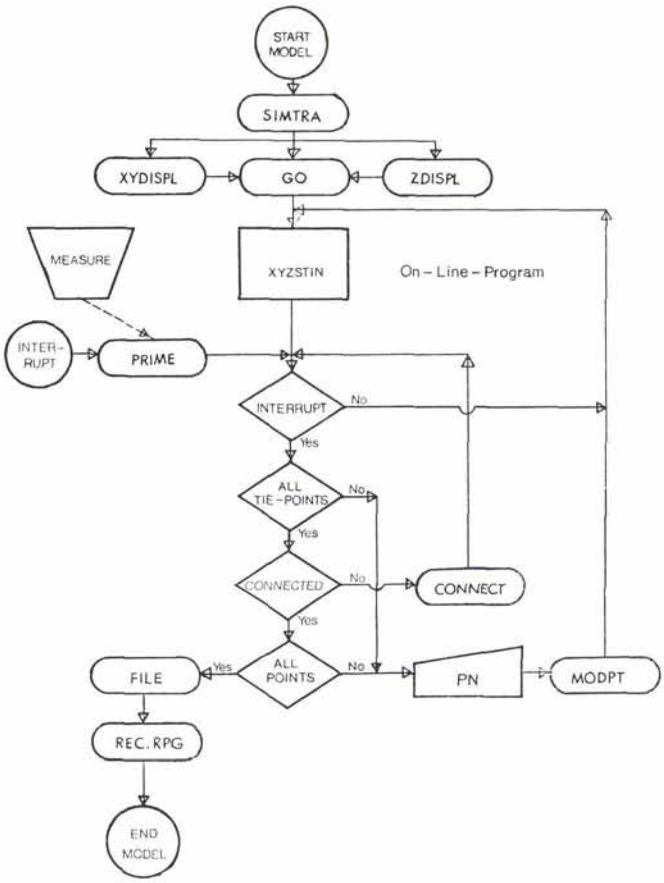

FIG. 9. Wang-700 operational flow chart of central portion of strip formation program from independent models.

the control points. The computer will then display the corrected orientation parameters which have to be set in the stereoplotter.

An instructive example of the practical usage is the formation of strips from independent models. Figure 9 shows the operational flow chart of a program designated *STRIPFORM*. Having completed the relative orientation of a stereomodel, the operator initiates the real-time program *SIMTRA* (similarity transformation) and either of three display routines *XYDISPL* (display *X*- and *Y*-coordinates), *ZDISPL* (display *Z* coordinate only), or *GO* (no display). The program reads the current coordinate values from the interface buffer, subjects them to a spatial similarity transformation, displays the transformed values and stores them into proper locations. The real-time program can be interrupted by the *PRIME* key. For recording the current coordinates, a point number *PN* is to be entered from the keyboard and another routine, *MODPT*, initiated. *MODPT* stores the coordinates in a sequential core memory file and gives control back to the real-time program. Program *CONNECT* has to be activated after all tiepoints to the previous stereomodel were measured and entered. The program determines the seven transformation parameters by a sequential linear least-squares approximation according to *SCHUT*.[5] Control is given back to the real-time program, and the new transformation parameters are used to compute on-line the strip coordinates of other model points. Finally, depressing the key *FILE* initiates a routine to prepare data to be recorded on magnetic tape cassette. As information from core to tape cannot be transferred under computer control, model data must be recorded by manual activation of the *RECORD PROGRAM* key.

A sort of supervisor program takes care of the coding tasks required for a simple systems monitor even a relatively unskilled operator is able to understand. The recorded strip coordinates obtained from the *STRIPFORM* program could later be used directly in a strip adjustment program. Investigations into a suitable program package are under way.

Conclusions

The aim of this paper is to show the usefulness of a simple and inexpensive, yet efficient photogrammetric on-line data acquisition system. Although the control computer of the system is merely a programmable desk calculator, interfacing it directly with a stereoplotter results in a variety of interesting and immediately usable features. The computer-based system is extremely flexible, totally user oriented, and bears some welcome by-products. Moreover, in a world where change *per se* is the fundamental criterion, a system flexible enough to cope with fast changes is more versatile and economically viable than dedicated hardware digitizers.

Acknowledgements

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