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Software Aspects of Analytical Plotters*

The properties of seven new analytical plotters, displayed at the XIII International Congress for Photogrammetry, are discussed.

During the exhibit of the XIII International Congress for Photogrammetry, held in Helsinki in July 1976, at least seven new devices were displayed which can be considered as belonging to the class of analytical plotters. Obviously the reason why there are so many analytical systems now being built is the drop in computer prices. On the average, computers of comparable capacity now cost only 50 percent of what they were costing four years ago. Process control interfaces, not the servo systems, have likewise been significantly reduced in price, although the optical-mechanical effort has remained the same. At a 33 percent overall cost reduction, the building of analytical plotters has become competitive with other types of plotters (see Figures 1 and 2).

Abstract: *The XII International Congress for Photogrammetry, held in Helsinki in 1976, displayed at least seven new instruments which can be classified as analytical plotters. This development is due to a substantial reduction in computer and interface costs. A further cost reduction is anticipated if the number of units produced increases. This will reduce the proportionally high software effort. A summary of the properties of the new analytical instruments is given and a discussion of these properties follows. The advantages of these instruments can best be realized by the development of task oriented modular programs.*

While it was always accepted that analytical plotters had their special advantages based on their software, they have now become attractive with regard to hardware. This is doubly significant because, in order fully to exploit the potential of analytical plotters, considerable software efforts are necessary. These add presently a great deal to the total system cost. In the future this cost can become negligible if software is produced in such a manner that it can be reused on other computers. There is a need for user oriented software documentation and standardization. Otherwise, software may remain limited, forcing the analytical plotters either to be mere substitutes for mechanical plotters, or the system costs will remain high because of the need to constantly redesign software.

Three types of instruments can be considered as analytical plotters:

(1) The Helava Concept-type "Analytical Plotters", which generate x, y, z pulses and compute photo-shifts by four servos plus table shifts by two servo systems.
(2) The "Digital Stereocartograph" type plotters, which digitize manually driven photo coordinates, compute from these the x, y, and z model and ground coordinates, and calculate y'' shifts for y-parallax-free observations and x'' shifts for the following of contours. For this task only two servos are needed in addition to the two table servos. Because of the slight move-

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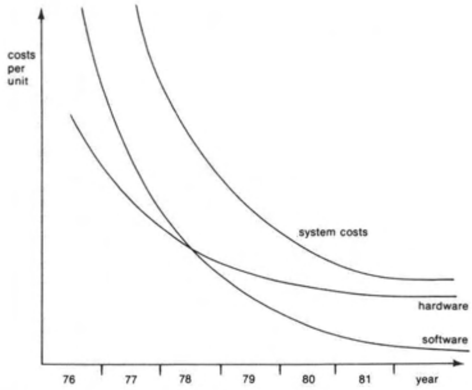

FIG. 1. Cost trends for control computers.

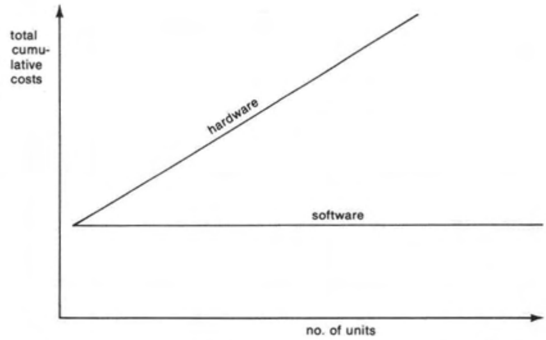

FIG. 2. Total cumulative costs as a function of the number of units produced.

ments involved, cheaper stepping motors can be used instead of servos.

(3) The "Stereocord" type plotters or image space plotters, which measure only image coordinates with x', y', and px''; it is possible only to calculate x,y,z and to drive the plotting table by two controls.

The historical development of analytical plotters up to 1974 is shown in Table 1.

The first commercially available analytical plotter, the O.M.I.—Bendix AP/C, was shown at the Lisbon Congress in 1964. Because of its delay line memory it was extremely difficult to program. At the Ottawa Congress in 1970 O.M.I. introduced the AP/C-3 with an IBM 1130 computer, which provided considerable potential. This opened the possibility in the civilian sector for program development. Because of adequate disk storage, new uses of analytical plotters became implementable. It should of course be remembered that military devices and that image correlation systems based on analytical plotter principles already offered the same possibilities, but at extremely high cost.

Table 2 gives a summary of the plotters developed since 1975. They are compared with the features of the AP/C-3 of 1972. They generally offer vastly improved computer capabilities, suitable for further software implementation. Paired with their four image drives, they offer possibilities for semi-automatic operation by driving to points based on ground, model, or image

TABLE 1. DEVELOPMENT OF ANALYTICAL INSTRUMENTS THROUGH 1974

Year	Model	Manufacturer	Special Features		Users
INVENTION					
1957	U. Helava				
PROTOTYPE & EARLY MODELS					
1963	AP-1	NRC Ottawa	delay line memory		private
1963	AS-11A	O.M.I.-Bendix	D.D.A.		military
1964	AP/C	O.M.I.-Bendix	delay line memory		private
INTERMEDIATE MODELS					
1968	AS-11A-1	O.M.I.-Bendix	BX 272—core		military
1972	AP/C-3	O.M.I.-I.B.M.	IBM 1130—core		private
SPECIAL MODELS					
1968	UNAMACE	Bunker-Ramo	TRW	automatic image correlation	military
1968	AS-11B-1	Bendix-O.M.I.	BX 272	automatic image correlation	military
1974	TA 3/P1	O.M.I.-Bendix	PDP 15	automatic image correlation	military
1972	Gestalt	Hobrough Ltd.	Nova	automatic image correlation	private
DIGITAL STEREOCARTOGRAPH					
1972	D.S.	Galileo	Laben minicomputer		private
IMAGE SPACE PLOTTER					
1974	A.P.P.S.	E.T.L., Fort Belvoir	HP 9810		military

TABLE 2. COMPARISON OF PRESENTLY AVAILABLE ANALYTICAL INSTRUMENTS

Manufacturer and year	Model	Computer	Core Storage	Disk Storage	Control	Digitization increment	Additional hardware	Cycle time
O.M.I., 1972	AP/C-3	IBM 1130	8K, 16 bit → 32K	512K, 16 bit	panel	2 μm	timed interrupt	3.6 μsec
Bendix, 1976	US 1	PDP 11/35	24K, 16 bit	1.2M 16 bit	CRT	1 μm	multilevel interrupt	900 nsec
Instronics-Gestalt, 1976	Anaplot	PDP 11/45	32K, 32 bit	2 × 1.2M 32 bit	CRT, panel	1 μm	double precision floating point, multilevel interrupt	—
Matra, 1976	Traster 77	Telemech. solar 16-40	32K, 16 bit	2 × 2.5M 8 bit	CRT	0.5 μm	coded linear encoders	750 nsec
OMI, 1975	AP/C-3T	PDP 11/35	24K, 16 bit	1.2M, 16 bit	panel	2 μm	multilevel interrupt	900 nsec
OMI, 1976	AP/C-4	PDP 11/03	24K, 16 bit	cassette	CRT	2 μm	—	1.2 μsec
Zeiss Oberkochen, 1976	Planicomp C 100	HP 21 MX	24K, 16 bit → 128K	4.9M, 8 bit	panel CRT	1 μm	floating point multilevel interrupt	650 nsec
Jenoptik, 1976	Stereo-dicomat	Kongsberg SM 4	16K, 16 bit	—	Teletype	0.625 μm step motors		—
Galileo, 1976	Digital stereo cartograph	PDP 11/05	12K, 16 bit	—	Teletype	1 μm step motors	—	900 nsec
Zeiss Oberkochen, 1976	Stereocord	HP 9810 or HP 9830	ROM 51 words ROM 1760 words cassette	—	HP 9810 or HP 9830	10 μm		—

coordinates, if appropriately programmed.

Due to only two image coordinate controls by step motors, the Galileo digital stereocartograph offers a more limited but cost-competitive version of an analytical instrument, while the Stereocord is only suitable for measurement with manual removal of y-parallax.

Compared to the AP/C-3 of 1972, all analytical plotters now have at least a 24K 16-bit core memory instead of an 8K memory. This leaves adequate room for additional programming and for control by a variety of devices such as the CRT and a teletype.

Whereas the CRT has certainly improved the effectiveness of a man-machine dialogue, the panel oriented standard-user friendly operation has persisted with some instruments, or it can be used in addition to the CRT.

The digitization increment of 2, 1, 0.625, or 0.5 μm is more of a token than a real standard, since most likely none of the instruments is designed for a higher overall accuracy than ± 3 μm. Nearly all analytical plotters use closed-loop servo systems to maintain this accuracy.

Some instruments use linear encoders (e.g., US-1, AP/C-4, Traster) and may be more dimensionally stable than those with pure spindle encoders (e.g., AP/C-3T, C 100). When the temperature remains constant, however, and when a "self-calibration" is occasionally performed, the 3 μm can nevertheless be maintained. Spindle encoders are generally easier to control servo vibrations, on the other hand.

Concerning the computers in use, the cycle time indicates that compared to 1972 the speed of computation has become three to six times faster. Interesting also is the added computer hardware, such as floating point hardware and multilevel interrupts, which greatly facilitate the programming ease in computer language and program structure.

The Digital Stereocartograph and the Stereocord, for example, use open-loop systems. Because step motors seem to work reliably nowadays or perhaps these instruments may be thought of as working with a more limited accuracy, this may be acceptable.

The usefulness of a larger core may be demonstrated by looking at the type of software needed for an analytical plotter. The software is composed of an operating system to be stored in core (monitor, disk operating, assembler, or compiler). It further includes applications software in core (real time program) or on disk (orientation programs, service program).

A 1972 system permitted a considerably less sophisticated operating system with a small common area. In a 1976 system the operating system may be eight times larger and the common area is 2.5 times as big for greater convenience.

In the classical real time program (for the AP/C-3) due to real time cycle restrictions of 32 msec at machine cycle times of 3600 nsec, one previously had to branch off into several loops in which slow changing expressions (such as photo and model corrections as well as panel interrogation and input output) were reached every $6 \times 32 = 192$ msec. Today, multiprogrammable priority interrupts permit working at various priority levels. The machine does not need to wait for one fixed clocked interrupt, but it can finish high priority computations first and then work on lower order priorities.

Analytical plotters have the most simple form of programming, corresponding to the collinearity approach of analytical photogrammetry. Digital Stereocartograph-type instruments are more complicated to program, particularly since the following of contours utilizes an iterative computation. Image space plotters, presently due to desk calculator limitation, offer only approximate solutions.

The present capabilities of analytical plotters are characterized as follows. They show improvements over standard type instruments in that they permit

- higher accuracy by self calibration;
- correction of various types of systematic errors (film, model);
- the extension of plotting limitation (focal length, enlargement ratio);
- the possibility to program for special sensor types;
- the capability of conducting interior, relative, and absolute orientation very much faster by semiautomatic procedures;
- the setting of a point by previously recorded ground, model, or photo coordinates;
- the use of the plotting table as an automatic coordinatograph with all plotting software consequences (points, lines, symbols, curves); and
- the storage of elevation sequences of grids in profiles, or of coded points and lines for the generation of DTM's or for use in automatic cartography.

The utilization of these capabilities for photogrammetric tasks will be useful only if the system of the photogrammetric processes starting from data collection via data input to end product (point coordinates, DTM, map, orthophoto) is considered. To improve the ease, reliability, speed, or accuracy of the operation process by an analytical plotter, special task oriented programs must be available.

In order to generate such task oriented programs, two prerequisites must be fulfilled:

(1) The operational capabilities and their steps must be programmed in modules.
(2) Such modules should be small enough for documentation on one page in the form of a Structogram such as that used in "structured programming."
(3) In this type of programming certain rules must be observed, whether the programming is done in compiler (orientation routines) or in assembler (usually real time operation). (No Go To's may be used.)
(4) The modules must be fitted together for a certain task.

It is to be hoped that by this type of programming routine users of analytical instruments will not be suffering from a "black box syndrome," but that they will be put into a position to change and modify the utilization of the equipment without too heavy an involvement. This would not be in the least interest of the instrument manufacturers.

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