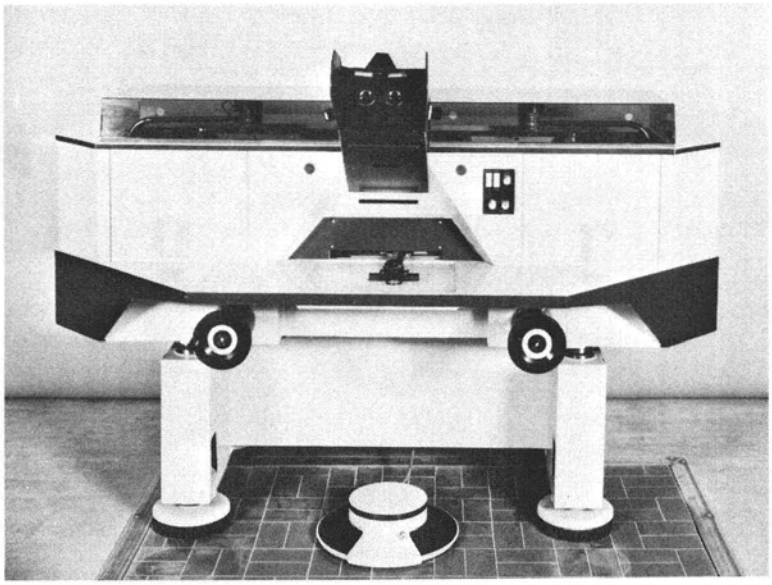

FRONTISPIECE. The OMI Analytical Stereoplotter Model AP/C4.

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The OMI Analytical Stereoplotter Model AP/C4*

The AP/C4 features computer controlled optics and a universal computer interface.

(Abstract on next page)

INTRODUCTION

WHEN TAKEN IN context of the time, that is, the state of engineering technology, the materialization of the first analytical stereoplotter in 1960 was a daring innovation. Cost of computers, reliability of their performance, intricacies of programming, limited knowledge of interfacing for real time computer-controlled operation, and temperamental servo-controlled systems were all factors which could easily discourage designers. It is history now that the major photogrammetric instrument manufacturers of the world were deterred. However, a determined and perhaps naive team drawn from OMI and the Bendix Research Laboratories, and encouraged by the U. S. Air Force, Rome Air Development Center, designed and manufactured the first analytical stereoplotter system, the AP/1, and, to our great relief, if not surprise, it worked!

The AP/1 was a forerunner of a variety of instruments generically known as analytical stereoplotters. The AP/1 led to the AP/2 which, in turn, generated the AP/C series and the AS-11 series. The primary difference between the two series is the limits on input

* Updated version of the paper presented at the Annual Convention of the American Society of Photogrammetry, Washington, DC, March 1977.

PHOTOGRAMMETRIC ENGINEERING AND REMOTE SENSING,
Vol. 43, No. 11, November 1977, pp. 1419-1425.

data which can be processed. The AP/C series is designed for conventional frame photography, although with a wide range of geometric characteristics. The primary limitation on an AP/C type is biological, that is, the limitation of the human eyes in their capability for fusing two disparate images for stereoscopic vision. The AS-11 series is unique in that the plotters are designed with computer-controlled optical systems to accomplish variable magnification and rotation of image independently in each optical branch of the binocular system in real time without human operator intervention. The AP/C systems, until the advent of the AP/C4, were equipped with fixed magnification optics except for special requests from clients but, in any case, were not controlled by the computer.

The computer-controlled optics of the AS-11 series provided a tremendous versatility for processing of input media. Special geometries peculiar to panoramic photographs, radar presentations, and infrared scans can be accommodated, but in order to accomplish such versatility a price has to be paid. Optical and electronic design of the system is more complex. The computer must have a greater capacity and the software is more complex. All these mean higher costs for the AS-11 systems as compared to the less complex AP/C systems. The economic justification for either of the two systems must lie with the user. We of OMI have found sufficient interest in both systems from the photogrammetric community to justify parallel development, manufacturing, and marketing.

The subject of this paper is the new OMI Analytical Stereoplotter Model AP/C4. The AP/C4 is an evolutionary step in the orderly development of the analytical stereoplotter concept. It is OMI's general strategy in this fast-moving world of technology to stay with the state of the art in order to increase performance and/or decrease cost of our systems whenever possible. Our transition from the first AP/C through models 2, 3, and, now, 4, reflect this approach. Until the AP/C4 most innovations and changes were primarily of an electronic nature. This is understandable when one reviews the startling expansion of the electronic and computer technologies in the past ten years. OMI produced the first AP/C early in the 1960's and now, less than 15 years later, we are introducing our fourth model.

When one examines casually the first three models, they look quite similar except for the computer and some optical and mechanical details not readily apparent. The AP/C4 has been thoroughly redesigned and has a completely different physical appearance.

Before engaging in a description of the AP/C4 it would be useful to note the salient features of its predecessors.

The AP/C (or AP/C1) was a direct modification of the early AS-11 series. Although the first analytical plotters were built for military mapping, the OMI staff were convinced that civil and commercial organizations would eventually accept the advantages of the analytical stereoplotter concept. The optical-mechanical structure of the AS-11 was redesigned to be less expensive while retaining the necessary high performance standards. This was accomplished by eliminating all components associated with computer-controlled optics and non point-perspective geometry. The computer and interface were designed and fabricated by the Bendix Research Laboratories at the request of OMI. Considering the state of the art at that time they did a magnificent job. OMI and Bendix continue to enjoy a fruitful col-

ABSTRACT: *The OMI Analytical Stereoplotter Model AP/C4 is the latest model of the AP/C series. It was introduced at the XIII Congress of the International Society for Photogrammetry in Helsinki in 1976. Whereas previous AP/C models were modifications of prior models, the AP/C4 is a completely new design incorporating several novel and, based upon OMI's experience, highly desirable features. Some features described are new lightweight and lower viewer chassis, use of linear glass scale encoders, built-in zoom optics, conversational man/computer control, universal computer interface, and utilization of microcomputer technology. The standard control computer is the Digital Equipment Corporation PDP-11V03 with CRT terminal.*

laboration in producing complex photogrammetric systems outside the immediate area of the AP/C-US1 competition and will continue to do so in the foreseeable future.

The optical-mechanical design of the AP/C viewer has been well documented. Essentially it is a two-plate stereocomparator depending upon high precision lead screws for accuracy of positioning. A unique design feature is the use of a mobile optical system for measurement along one axis and stage motion along the perpendicular axis. In our opinion this is more desirable than the more common technique of superimposing the travel of a stage along one axis upon a second stage traveling on the other axis which, of course, permits a fixed optical system. We have retained this feature through all our series. Other features of the AP/C were the use of a complex control panel with dedicated switches and servo motors of the AC type which are now considered obsolete. The computer was programmable in machine language only. Use of a higher level assembler or Fortran was not possible. This, of course, made changes in or additions to programs rather inconvenient.

The AP/C2 was a transitional model. It was substantially the same as the AP/C except that DC servo motors were introduced, thus increasing the reliability of the servo drive systems. Also, the AP/C2 introduced the idea of interfacing the unit with a commercially available, general purpose computer. Under the innovative guidance of Professor Konecny and his group at the University of New Brunswick, the unit was interfaced with the IBM computer 360.

FIG. 1. The OMI Analytical Stereoplotter Model AP/C3.

This experience encouraged OMI to proceed with a new interface design for the IBM 1130 which was a Fortran programmable, general purpose computer in what was then considered a low price field. The resultant system was designated the AP/C3 (Figure 1). This model did not differ materially, optically or mechanically, from the original AP/C model except in two very significant aspects. First, the reliability of the system was considerably improved. This was due to advances in computer technology which significantly improved mean time between failures. The second improvement was the ability to write programs in Fortran. This permitted the user of the system to control his own techniques rather than be dependent upon the manufacturer's philosophy of operation. A well-known complaint from photogrammetric instrument users is that the manufacturers are not always cognizant of the user's own peculiar needs and requirements. A further advantage to adopting a universally accepted, general purpose computer is the availability of a wide number of peripheral devices which a user can select, such as high-speed paper tape readers and punches, line printers, magnetic tape, disc memories, cathode ray tubes, terminals, etc.

The AP/C3 made its debut with the IBM 1130. However, computer technology moved along and it soon became obvious to the OMI staff that, with the introduction of the "mini computer," the IBM 1130 was becoming obsolete. These mini computers were very powerful in their capabilities, relatively inexpensive, and generally highly reliable in performance. Certain models were ideally suited to the tasks imposed by an analytical plotter system. OMI considered the PDP-11 (Digital Equipment Corporation) series to be ideally qualified as a control device. The manufacturer had a worldwide sales and support organization. The unit had been well received in the market and was considered highly reliable. The software library was extensive. Peripheral devices of all types were available. Accordingly, an interface was designed and the system was offered for sale.

This very briefly sums the progress up to the introduction of the AP/C4.

AP/C4

The OMI Analytical Stereoplotter Model AP/C4 (Frontispiece) is the latest production model of the AP/C series which began in 1963. Unlike previous models, i.e., the

AP/C2 and AP/C3, the AP/C4 is a complete redesign. OMI decided that technological progress since the initial model was produced could not be exploited adequately by introducing another modification. The time had come for a complete restudy of the function and design for the analytical stereoplotter. Over 15 years of company experience in this highly specialized area was concentrated upon the task. Computer technology, man/machine interfacing, optical-mechanical techniques, and the requirements of photogrammetrists in today's environment were among the important areas to be considered. A most important factor was the economic one. OMI's experience in marketing analytical plotters has made the company very sensitive to the most universal and, sadly, unqualified criticism, that analytical plotters were not practical because they were much too expensive. We doubt that such criticism would hold up under a close cost comparison with digitized analogue instruments and their productive capabilities.

The AP/C4 system, like all analytical stereoplotters, can be broken up into separate components for discussion and description: a stereo viewer console, an *X-Y* coordinatograph, a digital computer, and an interface assembly.

When the design team for the AP/C4 established its objectives, the following points were given highest priority:

- Performance accuracy equal to the previous AP/C3 was to be maintained. This performance exceeded the reliability of input data.
- The selling price of the system was to be the absolute minimum consistent with performance standards. The era of competition in the analytical plotter field had arrived. OMI is no longer the only manufacturer of analytical stereoplotters. It is our intention to retain competitive leadership in this area.
- Human engineering, that is, man/machine interface, should be a culmination of our manufacturing experience and the experience of our customers.
- System reliability, or mean time before failure, must be commensurate with the state-of-the-art possibility and mean time to repair must be extremely short. Preferably, photogrammetric operators should be capable of analyzing and repairing most failures without requiring special assistance.
- System operation should be self-instructive and require minimal training beyond an elementary knowledge of stereoplotting.

THE STEREOVIEWER

The AP/C4 stereoviewer is a new design: compact, efficient, and attractive. It was introduced to the public for the first time upon the occasion of the XIII International Congress for Photogrammetry at Helsinki in 1976. When compared to its forerunner, the AP/C3, it gives the impression of a smaller and lighter unit with a lower silhouette. This was the desired effect. OMI experience indicated that a great deal of supporting casting was not essential to stable performance. The AP/C3 design tended to isolate the operator from direct visual observation of the plate holders except, of course, through the optical train. A consensus of operators indicated they preferred to have direct observation of the stage travel, particularly when the plotter is under computer control, such as when visiting points during orientation procedures.

The optical system has been completely redesigned to require fewer components and yield higher resolution and brightness. Continuous zoom magnification is provided with a 2.5× range. It is independent for each eyepiece or simultaneous for both eyepieces. Fixed opaque or variable illuminated marks are provided. Optics move along the x axis and the photo stage moves along the y axis. These mechanically independent motions preclude errors normally associated with stage-on-stage arrangements.

Mechanical displacements are made by lead screws activated by servo motors directly secured to the lead screw shafts. This arrangement eliminates both gear box play and disturbing gear noise. Noise level of the operating system is pleasingly negligible.

Measurement of displacement is accomplished through linear glass scale optical encoders which allow an axis accuracy of ±2 micrometers.

OPERATIONAL CONTROL

It is difficult to categorize the control elements concerning whether they should be assigned to the stereoviewer, the interface electronics, or the computer itself. Perhaps, inasmuch as the control elements are physically located on or near the stereoviewer, they are best described as being a part of the viewer.

Of all the elements of the AP/C4 system, the controls have received the most man-hours of analysis. The options on design of the comparator and the *X-Y* plotter, the selection of computer, and even the design of the electronic interface are relatively limited as compared with the choices for controls and communication between man and system. Perhaps here, more than anywhere else, experience is a most valuable asset.

How can the operators task be made comfortable, simple, and yet efficient? How can the process be expedited for, after all, time is most important? Furthermore, what checks should be available to avoid costly errors? A familiarization with how analytical plotters are used and how they should be used is most desirable for the designer.

In the past our control panels have been primarily an array of specific designated switches and the read-out has been a bank of digital numbers. Alternate visual read-out was a hard-copy typewriter. New options now available in the form of inexpensive cathode ray terminals and fast line printers have given us new possibilities. Our design philosophy for the AP/C4 has been to greatly limit dedicated switches to the most-often-repeated functions. All other switches which are provided have their functions defined by software. This gives the user tremendous versatility. Naturally, we provide recommended software with our choice of switch functions; but this does not preclude the customer's freedom of choice. A high degree of redundancy is characteristic of our solution. Communication with the computer and the servo system can be accomplished with control buttons, CRT typewriter panel, hand and foot wheels, joy stick, and, unique with the AP/C4, a digitized pantograph.

The switch buttons, hand wheels, and joy stick controls need no further description; they have been used on prior models and their functions are well known. There is some novelty concerning the use of the CRT terminal. The AP/C4 system uses the CRT as a conversational communication device as well as an instructional link between operator and computer. This is particularly valuable in training operations. The operator is presented, on the CRT face, with options for various photogrammetric operations and instructions on how to select them. He is also admonished when he has made an obvious error. The CRT face is the standard read-out for all data called upon from computer memory. Photogrammetric parameters, coordinate data, and other digital data can be continuously displayed and updated in real time. The typewriter panel of the CRT is an alternate means to the push button switches for communication with the computer.

The most novel feature of the AP/C4 control system is the digitized pantograph. The AP/C4 model is the only analytical plotter which features this device. It consists of a handgrip suspended over a small light table located in front of the operator, directly below the eyepieces. Movements of the handgrip, manually controlled by the plotter operator, are duplicated by the floating point in the X-Y plane of the stereo model. The ratio of movement between handgrip and mark is controllable by the operator in a very convenient fashion from 1:1 to 100:1. This is remarkably convenient for moving rapidly across the model to the vicinity of a target of interest and then approaching the exact target with micrometric sensitivity. The ratios of motion are software-determinable and may be increased or changed as desired. As mentioned previously, directly below the handgrip is a light table which can accommodate an aerial photograph or transparency. Normally this photograph would be a duplicate of one of the stereo pair in the plotter. A cursor attached to the handgrip permits the operator to track the floating mark displacement in the model when the 1:1 scale is utilized.

THE COMPUTER

OMI constantly reviews the progress of computer developments with the prime purpose of selecting for the AP/C systems a control computer that has the most desirable combination of characteristics for the purpose. Among these characteristics are low cost, reliability of performance, adequate computer power for the task, worldwide sales and service, and software backup. Currently, we have selected the Digital Equipment Corporation PDP-11V03. It is significant to note at this point that, because the OMI-designed interface is quite universal, special requests for the AP/C4 to be integrated with other types of modern computers can be accommodated.

The PDP-11V03 is an unusually compact unit. It is an integrated hardware-software system designed to offer powerful and flexible computation resources at low price. The standard configuration for the AP/C4 includes 32K semiconductor read-write memory, dual-drive floppy disk system, terminator-bootstrop module with DMA refresh, a VT52 DEC scope or LA36 DEC writer 11 input/output terminal, and a caster-mounted cabinet with power distribution panel.

INTERFACE

A very important element in the analytical stereoplotter system, but one which is not often commented upon, is the interface design for connection between the central processor and the photogrammetric system, i.e., the stereo viewer and coordinatograph. This unit, which is physically not obvious, is truly the heart of the system because it is responsible for circulation of signals from viewer

and plotter to computer and back again. It interrogates data inputs, decides priorities, controls servo systems, and displays data.

OMI is particularly pleased with its newly designed interface. Until this design was implemented we had a continuous problem, both technically and financially, of custom designing a new interface for each change of computer. This was difficult. We desired to take advantage of the latest developments in computer technology in order to bring to our clients the best and lowest price system possible. Improvements and economical savings in stereoviewer and coordinatograph designs were relatively slow. Software, thanks to the higher level language, was becoming a manageable economic item with some degree of stability. However, advances in micro-electronic technology produced startling changes in computer design and costs. This at present is a continuous process. To take advantage of continuous new offerings in order to assure ourselves of a highly successful competitive position would require the design of a new interface at frequent intervals. This is prohibitively expensive both from initial effort point of view as well as cost of maintaining an inventory for repair of various models. The ideal answer to our problem, which until now was quite elusive, was a universal interface. Such an interface would, with minimal effort, communicate with almost all modern computer architectures as well as anticipated designs for the future.

The AP/C4 interface has attained this highly desirable objective. Although, as stated previously in this paper, OMI has standardized on the PDP-11V03 computer for the AP/C4, it is a relatively simple matter to provide an alternate computer if a client so desires.

X-Y PLOTTER OR COORDINATOGRAPH

The design of the AP/C4 coordinatograph departs from previous models in several details but, fundamentally, the performance is quite similar except for one very important change in basic concept. Previously the plotting table, as with analog instruments, was treated as a peripheral of the stereoplotting chassis. The functional philosophy of the AP/C4 is that the stereoviewer and the coordinatograph are independently communicating peripherals of the control processor. This approach in no way conflicts with the classic relationship between viewer and plotter; however, it greatly facilitates and enhances the possibilities of utilizing the *X-Y* plotter as a computer controlled independent unit as well as permitting background-foreground performance of the system, i.e., assuming the computer has adequate power. This would permit, for example, that during aerial triangulation operations or other tasks not requiring graphic output, the plotter could be performing graphic tasks on an entirely different problem. A further advantage for the user is the ability to utilize any *X-Y* plotter compatible with the selected computer. The user is not limited to using exclusively the standard unit supplied by OMI.

In operation the coordinatograph normally supplied is quite conventional for an analytical plotter. The standard unit is 1050 by 1100 millimeters in range with a backlighted stage. A large selection of tools and accessories is available, including a closed-circuit TV. Ratios between stereomodel coordinates and plotting coordinates are digitally established in the computer. Any combination of two of the three axes can be plotted and each axis can be assigned its own scale.

THE SOFTWARE

The analytical plotter system can be, in an oversimplified manner, compared to a living organism. We can consider the measuring and drawing devices, that is, the stereoviewer and coordinatograph, as the skeleton and muscle structure. The computer and interface would be the brain and nervous system. It is the software that is the mind, the thinking element, as contrasted to the nonthinking virgin unpatterned circuitry of the computer and interface. This is an amusing if dangerously simple analogy.

Following this analogy, we require for optimum performance a strong body and a good mind. The body is determined in a rather rigid fixed pattern with slight potential for improvement. OMI, with its many years of experience in construction of analytical plotters, has learned how to produce a powerful body and the possibilities for improvement are somewhat restricted. This is not the case for the mind or, in the context of the analogy, the software. We are continuously educating our animal and will continue to do so with little limitation in sight. This is the true beauty of the analytical concept!

There is considerable information available on analytical plotter software, both that of OMI and of other systems as well. The software can be categorized in three major groups if we exclude diagnostic routines and DEC operating systems and concern ourselves with photogrammetrically pertinent groups. We have the real time software that

is responsible for the relationships of stage, photo, model, and ground coordinates. We have the basic operations peculiar to setting up the stereo model, such as interior orientation, relative orientation, absolute orientation, and routines for correction of definable systematic errors. Then we have specific application programs which permit exploitation of the stereo model information such as, for example, aerial triangulation, profiling, digital terrain modeling, adjustment of data, resource inventorying, highway construction, and many others limited only by our own ingenuity.

The real-time and fundamental orientation procedures are well-known now and any manufacturer of analytical stereoplotter systems should be capable of offering efficient software for these purposes. It would be difficult for OMI to claim a great superiority or uniqueness in this area, just as it would for any other manufacturer.

It is in the area of application programs that initial competition will be strong. The word initial is used advisedly because there is little doubt that imitation will be quick and successful. This is a pattern we have seen often enough in the data processing field.

To offer a detailed summation of our software routines would be redundant and tiresome. I prefer to leave that to our promotional literature. OMI does provide the complete package of orientation routines and application programs which continue to expand. Except for our real time programs, which are in assembler language, we use Fortran with all its attendant advantages.

Conclusion

It is perhaps pertinent to make a general observation about analytical stereoplotters. Prior to the introduction of analytical stereoplotters, the analog stereoplotter was the only type. Development of the analog concept fought a continuous battle with the input medium, the aerial photograph. At times the stereoplotter was capable of a higher degree of information processing than the input contained. At other times the aerial photo contained more information than the plotter could extract. These conditions varied as the science and technology of the two efforts competed with each other. At the time when the analytical stereoplotter was introduced, the photograph contained more data than "first order" stereoplotters could measure. Analog techniques were just not capable of measurement to the order of accuracy required to fully extract the metric data contained in good aerial photography. The analytical stereoplotter has once again turned the situation around. The measuring potential of the analytical stereoplotter exceeds the metric accuracy of aerial camera film. All analytical stereoplotters now offered commercially have this potential performance capability. In the near future the buyer of an analytical stereoplotter will accept its accuracy as a matter of fact. He will concentrate upon such factors as cost, reliability, ease of operation, and serviceability.

In summary, I have attempted to present a brief description of our most recent model of analytical stereoplotter, the AP/C4, interjected with some personal observations on analytical stereoplotters in general. OMI, which for years has enjoyed a singular position as a manufacturer and supplier of analytical stereoplotters, now finds it has competition. This is neither unexpected nor unappreciated. We all recognize that competition inevitably results in a better product for the user which, in this case, is the photogrammetric community.

National Science Foundation Fellowships for 1978-1979

The closing dates for filing applications for Graduate Fellowships, open to students beginning graduate studies, and for National Needs Postdoctoral Fellowships, open to persons holding a Ph.D. degree for less than four years, are December 1 and 5, 1977, respectively. For further information and application forms please write to:

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National Research Council
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