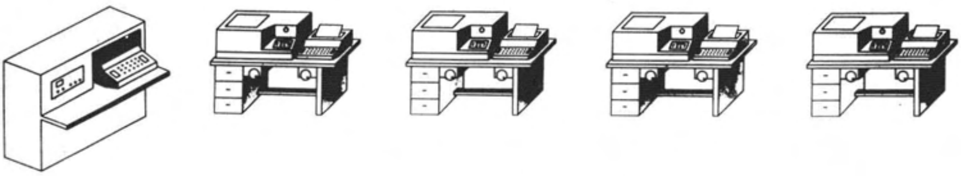


FIG. 1. The APM Monocomparator System: automatic carriage movement; expansible from one to four units; recording from memory; compensation for errors; independent operation of units; optional magnetic memory; computer for analytical work.

U. V. HELAVA
Ottico Meccanica Italiana
Rome, Italy

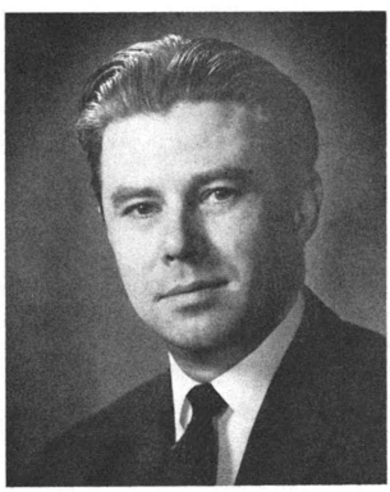
A Family of Photogrammetric Systems

Data processing units may include comparators, coordinatographs, a computer, magnetic tape, etc., to form a flexible and expandable system.

(*Abstract on next page*)

NEARLY ALL photogrammetric instruments can be considered to be special data processing devices. A study of these instruments, and their performance from this point of view is most instructive, in particular if this study leads to a constructive comparison with other data processing systems. Such a comparison becomes more interesting and assumes added significance on account of the special requirements set by the photogrammetric problem for the input and output capabilities of the systems. In general, the main bulk of the input information is contained on photographs, but in addition to this, numerical data and instructions from the operator must be accepted by the systems also. Corresponding input devices are x-y measuring engines with suitable viewing systems and/or opto-electronic sensors, magnetic or paper tape readers, dials, keyboards and various manual controls. The output is usually in graphic form, a contour or profile plot, or an orthophotograph. Often, however, numerical records also are needed. Corresponding output devices are precision coordinatographs, orthoprinters and various digital recording devices, such as magnetic tape units and teletypers. Between the input and the output there is the data processor for which role the electronic computer is almost exclusively used outside photogrammetry. It is gaining acceptance also in photogrammetric-cartographic field.

The Analytical Plotter is an example of a photogrammetric data processing system. In this instrument the input devices, the AP/C



U. V. HELAVA

computer and the output devices have been linked together by suitable data transmission links to provide an advantageous solution for a specific group of problems. However, once the basic components and the links between them are available, systems for solving various problems can be effectively constructed by connecting the basic components in a suitable way. This basic philosophy has lead to the development of a family of photogrammetric-cartographic systems. Main features of some representative members of this family is described below.

A TYPICAL MEMBER of the family is a monocomparator system for analytical photogrammetry, shown schematically in Figure 1.

ABSTRACT: *The concept of the analytical plotter integrates the basic components of photogrammetric data processing into one system that includes all necessary links between the different components. In the analytical plotter these basic components—the optical mechanical measuring part as the input unit, the electronic digital computer as the processing unit and the plotting table as the output unit—are connected and used in a specific way so as to solve a specific group of problems. There is, however, no reason why the basic components and the links between them could not be used in a variety of ways to provide combinations that solve a variety of problems. This fundamental concept has led to the development of a family of O.M.I. systems. Each of the systems has been designed to offer an advantageous solution to a specific problem, both from the technical and from the economical point of view. Expansibility is a property common to all these systems and exchangeability and compatibility within the family of systems has been realized wherever practical.*

This system has been designed for those users who have a task of mass producing comparator measurements for analytical photogrammetry. The computer part of the system is the AP/C computer built by Bendix. This computer has all the necessary real-time input-output channels already existing and it can perform its tasks in this system with little more than program modifications. The measuring part is the OMI-monocomparator TA-1 which is equipped with servo-motors and input encoders compatible with the AP/C computer. These comparators have been checked numerous times and they give the value of s_0 between 1.5 and 2.0μ. Each monocomparator is equipped with its own control and display panel. One computer can handle the real-time operations of up to four measuring units.

The control panels give the operators of monocomparators the necessary means to make the measurements in a most efficient manner, with the aid of the computer. When the operator pushes down one of the push-buttons on the control panel, the computer drives the carriages so that one of the fiducial marks of the photograph comes into the field of view of the instrument. This movement is automatic and rapid. The operator then makes collimation to the fiducial mark by using the handwheels, sets the identification number and pushes a button which causes the computer to record the coordinates of the measured point. By operating other buttons, one can instruct the computer to drive the carriages to the other fiducial marks and to the vicinity of the customary orientation points. These features make the measuring process both fast and convenient.

ADDITIONAL CHARACTERISTICS can be "custom tailored" into the system by changing the computer programs. Depending on the accuracy requirements, a more or less complete method of introducing calibration corrections may be employed. Similarly, changes in the output format and code may be incorporated, or the recording may be made after some transformation, e.g., one which gives the coordinates of the measured points in the coordinate system defined by the fiducial marks.

In addition to the high speed of operation which is of great economical significance, the system has also other features that have an economical meaning. The system is, first of all, expansible. Thus, it is possible to start with one or two measuring units and later acquire a third and a fourth comparator. It is interesting to note that the per unit cost decreases considerably with an increasing number of measuring units.

The AP/C computer may be used to carry

out analytical aerial triangulation using the measured coordinates. This task, however, has to be carried out at a different time. This is not a serious drawback, because the necessary computation time is only a very small fraction of the time needed for the measurements. Therefore it should not be difficult to overcome the organizational difficulties of arranging sufficient time for computation, e.g., during a different shift. In this respect the new AP/C magnetic tape unit, now being developed, will be of great importance. It will speed up the coordinate recording process, eliminate transcribing mistakes, and greatly increase the speed at which the different programs can be called into action.

Last, but not least, the system is compatible (as far as is practical) with other members of the family. The same magnetic tape unit, for example, is used with the AP/C and with other members of the family. Also, format, code and program compatibilities are attended to. Thus, the adjustment programs now being developed for the AP/C are available to the users of the monocomparator system.

EVEN THE AP/C lends itself to advantageous modifications when analyzed from the systems point of view. The AP/C was conceived for a certain group of problems. For some of these problems the total AP/C system may include excessive hardware, for some others its capabilities may not have been fully exploited with the original hardware of the system. Such a situation is obvious if aerial triangulation is considered. For this purpose the plotting table is redundant and one could describe a triangulation system as either an AP/C without a coordinatograph, or a stereocomparator with an on-line computer. For an organization which has continuous demand for aerial triangulation these are efficient triangulation systems. Omitting the plotting table from an AP/C is not simply a "gimmick" to obtain a new "system." Instead, it provides for some outstanding features.

The most important one of the new features is the new relative orientation program just completed for the AP/C. This program is made possible by the high speed real-time performance of the AP/C computer. It utilizes a unique method of linearization of the formulas for the least squares solution. The linearization is performed by perturbing the parameters one by one and by calculating the results using the real-time programs of the AP/C. Thus, the linearization is always correct and includes all factors, also the corrections. Theoretically, then, this is the best method of linearization, which to my knowledge is not employed in any other analytical triangulation system, even in those designed for large computers. In other ways also, the method meets well all the standards that may be set for an analytical orientation method: it is general, provides space for a sufficient number of orientation points, does not require a repetition of measurements and includes in its output an indication of the quality of the relative orientation achieved. As it can be seen, this system offers the fullest analytical accuracy possible with the important additional advantage that the results can be checked and visually verified immediately. Thus, it can be rightfully said that the system combines the advantages of both the analytical and the analog methods.

This is not all, however, It also offers advantages not found in either of the two well-known methods mentioned above. The most important of these advantages have to do with automation and are outside the scope I have set for this paper. There are, however, some that may be mentioned in this context. One such feature has to do with the identification of carry-over and scaling points. The triangulation method is such that the coordinate transfer is executed via coordinates of the air stations. Therefore, the coordinate reference is not lost while switching from one model to the other and the exact location of any point on the "old" photograph can be found easily by setting its model coordinates. The carriages then move automatically to such a position that the measuring mark coincides with the point.

ANOTHER FEATURE has to do with data transfer. The triangulation and its follow-up adjustment processes are being designed for system compatibility so that copying and transcribing tasks are nearly completely eliminated and the manipulation kept to a minimum. This advantage is further amplified with the advent of the magnetic tape unit. With the aid of this device, the pertinent programs can be permanently stored on the tape, and the storage and manipulation of measured and control point coordinates can be handled completely internally by the computer.

It is also appropriate to mention the organizational convenience of having the complete data processing machinery within the competence and jurisdiction of the photogrammetric organization. Large computers operated on the time-sharing basis can un-

FIG. 2. The AGR Analytical-Graphical Rectifier: uses analytical four-point method; may be programmed to perform more complex transformations; determines transformation coefficients automatically; transformation with analytical rigor.

deniably show the lowest cost per operation if the calculations are based on the computation phase only. However, if one also takes into account the organizational aspects, the cost of data manipulation and/or data transmission links, effects of delays and mistakes, and lack of complete professional control by a competent photogrammetrist, then the advantages of a large computer over a sufficient powerful smaller one under optimum control and usage are very doubtful.

A STUDY OF THE AP/C computer has shown that with relatively minor alteration it can be used to drive:

- An aerial triangulator and an independent automatic plotting table simultaneously;
- An aerial triangulator and two independent automatic plotting tables simultaneously;
- Normal AP/C—plotter and an additional independent plotting table simultaneously.

These properties demonstrate the flexibility of the AP/C concept and can certainly be put to use with economical advantages by alert users. It suffices to point out that an AP/C triangulator can be expanded with an automatic plotting table at a reasonable cost and that in this case it can be used also as an AP/C; that an AP/C can be expanded at a reasonable cost with a second automatic plotting table and the total equipment can be then used in any of the combinations mentioned above.

The AP/C computer is also able to drive up to four independent plotting tables simultaneously. This system is also expansible. One can start with the computer and one coordinatograph. Undeniably, such a system would be an expensive automatic plotting table. Equally true, it would be a very flexible and versatile plotting table which, due to the presence of the computer, is capable of executing most intricate and complex operations, even if necessary with on-line, real-time transformations and data processing. Such a problem may arise for example when converting results of surface fitting or expressions of other mathematical models into a graphical form. On the other hand, if there is at hand a large task of plotting points, the expansibility feature quickly reverses the per unit cost situation.

THE BASIC POINT of view of the systems approach that brings fruitful results when looking for solutions to existing or anticipated problems in photogrammetric work can also be applied to related fields. For example, simple measuring devices and the magnetic tape unit (or units) can be connected to the AP/C computer in a manner suitable for digitizing map information. As another photogrammetric-cartographic example, a system consisting of up to four analytical rectifiers may be cited and is shown in Figure 2.

Each unit of this system uses a monocomparator for input and a coordinatograph of suitable dimensions for the graphical output. The computer is programmed to transform in real-time the input to graphical output according to the formulation that is a mathematical equivalent of the well-known four-point method. The program includes, in addition, facilities for automatic determination of the coefficients of the transformation.

The system is intended for map revision in cases where the terrain conditions permit the approximation of considerable areas by a plane, either horizontal or inclined. The operator uses the handwheels of the monocomparator to move the measuring mark to one corner point of a quadrangle (which can be approximated by a plane) and after activating a switch uses the same handwheels to move the pencil (or microscope) of the coordinatograph over corresponding corner point on the map, mounted on the coordinatograph. He then pushes a button to indicate to the computer that a pointing has been made, and moves to the other three "control points" one by one. When four points have been so measured the computer is able to derive the transformation formulas. Any details within the quadrangle can then be transferred from the photograph to the map.

Obviously other formulations also can be employed for frame photography and, with suitable development, even other than normal frame photographs could be used.

STARTING FROM THE basic components—comparators, coordinatographs and a powerful control computer—and adding such components as a magnetic tape memory unit, a fast paper tape reader and a punched card reader, possibilities are created for the efficient design of a family of expansible and, to a great extent, compatible, photogrammetric data processing systems. In this paper some representative examples of such systems have been described. It is obvious that this presentation does not exhaust all the possibilities of the systems approach. Numerous variations and many additional systems can be put together in the same modular fashion. It suffices to remind one that the already-existing experience and knowledge in the field of automation in photogrammetry may be called upon to add other dimensions to the array of components that may contribute to a progressive extension of the system concept.

Articles for Next Month

Kenneth Reynolds and Stuart P. Roberts, A Digital Readout and Recording System for the B8 Plotter

Raymond M. Bateson and Kathleen B. Larson, Compilation of Surveyor Television Mosaics

Walter R. Ambrose, A Radar Image Correlation Viewer

Frank W. Trainer and Robert L. Ellison, Fracture Traces in the South-Central Shenandoah Valley, Virginia

Edward A. Gill, Coal Exploration and Photogrammetry

Gordon Kitching, The Versatile Planimetric Compiler

M. R. El-Ashry and H. R. Wanless, Sequential Aerial Photography and the Study of Shoreline Features and Shoreline Changes