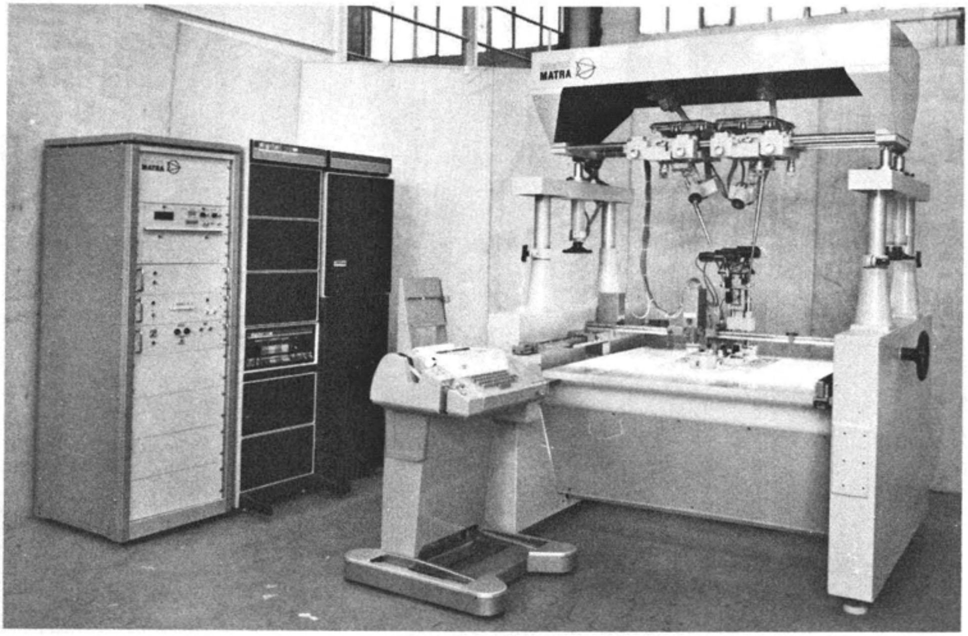


FIG. 1. "Short" system designed by MATRA for photogrammetric automation.

DR. B. L. Y. DUBUISSON
20 Avenue Paul Appell
75 014 Paris, France

Automatic Photogrammetric Cartography

Because of the arduous and painstaking nature of cartographic drafting and the scarcity of those highly trained artisans, together with improvements in applicable computer hardware and software, the time has arrived for the application of specially programmed digital drawing machines.

(Abstract on next page)

DIGITAL DRAWINGS—WHY MAKE THEM? HOW TO MAKE THEM?

DIGITAL DRAWINGS AND MAPS are established after determining the values of the coordinates of the points composing them. Their origin can be traced to the very start of geographic sciences because, except for the plots made on the surveyor's table and by graphical stereoplotting, all cartographic drawings are composed of conventional representations on points defined by coordinates.

From the beginning, large-scale maps of surveyors are based on calculations in coordinates serving to define the perimeters and the surface-areas, and then finally to plot the graphical drawing that forms the definitive document. Of course, these digital drawings and maps comprise a non-negligible part of graphical filling in.

Recently, however, the number of graphical plotting processes still employed fell off sharply with the advent of new topometric facilities and computers. In this connection mention should be made of the general au-

ABSTRACT: *Some general remarks on digital drawings and the devices that have had to be created to produce a truly complete automation of photogrammetric maps. Description of digital systems of coded data acquisitions; adaptations performed on various types of optico-mechanical instruments; systems grouped together in complex acquisition systems. After three years operating several systems, the findings are given on the extreme modularity of automatic photogrammetry and some forecasts are made on the phases of its future expansion.*

tomation prospects offered by instruments for the electromagnetic recording of angles and distances, such as the A. G. A. 700 and the generalization of the presence of mini-computers.

In the photogrammetry itself, the digitization methods have been developed through the frequent use of detectors in the model supplying, by digital-numerical transformation, the coordinates measured in this model space. This development, it should be noted, has been caused by the development of analog aerotriangulation and the requirements of civil engineering. But we are still far removed, at this level, from what may be called a digital drawing, in its present conception.

Today one may define a drawing or an integral digital map "as a map which is solely formed of alpha-numerical data, classed in files, and of a nature to supply automatically the partial or total expression of the space at an arbitrarily fixed scale".

This definition implies the need to know the points of the tracing in orthogonal geographic coordinates (X, Y, Z), and to associate with each point two items of information: the *form code* for the tracing of the lines, and the *function code*, both for the conventional expression required for the drawing and for the classification of types of objects.

The *advantages of such "integral" digital drawings* are considerable; to state these advantages amounts to mentioning the very economic requirements which have entailed their creation. One should note that:

- The value of the stored data is integrally preserved because its preservation does not depend on a graphical transfer (which is always imperfect) made on a support generally unstable with respect to time.
- The technological developments in hardware and software allow a complete automation, right up to the graphical expression, if the data acquisition is digital.
- The relative independence *vis-à-vis* the scale of the graphical expression which will be most often used. The magnetic tape controlling the drawing may be prepared with conventional instructions linked to the scale of this drawing, and this latter may be made at the desired graphical dimension on the drawing machine. What is important is that the same address files of coordinates and instructions may serve as a base for drawings and maps on all scales and at all instants, especially if the card files are kept updated with the modifications embodied in the meantime. This independence, extremely valuable, is obviously only *relative* because the numerical accuracy of the coordinates and the superficial density of the data, once the acquisition has been performed, are invariants of the system. There is therefore an upper limit to the possible graphical drawing scale.
- The drawings and maps are always intended to allow studies, or to make decisions in a certain well-defined political, economic or technical field. This is why the universal graphical maps are rarely used *straight off the board*. The utilizer makes a selective extract, prior to processing it; this forms a *thematic map*, with unnecessary and cluttering details removed. The great utility of the complete digital drawing resides therein; one may extract from it, when needed and in accordance with the utilizers requirements, the data selected by computer and drawn automatically in thematic form.
- Information contained in the large collective card files, such as that dealing with the population, the economy, industry, fiscal matters, must be located geographically. Thus, in all countries of the world, a need has existed for digitized location data processing which only digitized drawings can satisfy.
- Finally, the topographic and cartographic drawing is an arduous and costly work of an artistic nature, performed by specialists whose number and qualifications are tending to fall off. The time has therefore come for this work to be taken over by specially programmed drawing machines. This can only be done through the digital drawing.

METHOD OF ESTABLISHING DIGITAL MAPS

Maps are made by land surveys and result from the topometry, or else by aerial photography. One should distinguish first of all the maps and drawings plotted directly in the digital mode, and recorded as such with their codifications, allowing the subsequent classification in a card file, and the selection in a computer prior to their drawing.

Next may be distinguished those maps already drawn conventionally in the graphical mode; the graphical plotting of the coordinates of the points and of the required codification is done later. This is done, of course, with digitizing tables in X and Y, equipped with their peripheral units. Such a practice invevitably entails a loss of data because a previous passage by graphical channel, has taken place.

Prior to the advent of digital systems (early 1971), the possibilities of digital photogrammetric plottings were offered by the following facilities:

a) analytical plotters (APC), perfectly suitable, through their principles, for dealing with the trend to integral digital methods. For various reasons, they have not been instrumental in achieving an integral automation, truly operational and industrially productive.

b) recording systems developed in numerous photogrammetry optical-mechanical instruments, currently available. The system is slow, firstly because it is necessary to perform manually the marking of the points taken on a associated document, i.e., a photograph. Next, and above all, as the system only supplies the coordinates in the *machine* space, and because one must then transform them off-line into geographical coordinates by transfer with a computer unit separate from the restitution workshop. The result is a break in the production continuity, entailing technological difficulties, and responsible for low productivity.

The general and widespread use of digital photogrammetry, and its orientation towards automatic photogrammetry have therefore led to a complete re-evaluation of the system.

Digital Systems in Service

One system, called *shortsystem*, has been designed by Matra for photogrammetric automation (Figure 1). The program proposed within the concept of the digital system of photogrammetric acquisition comprises five main phases:

- Performs of the measurements at a high rate, simultaneously with the encoding of the data for their subsequent classing, including the indications for the preparation of the maps, such as the toponymy.
- Transforms the *machine* coordinates into orthogonal geographical coordinates and their recording with the encoding on a fast memory, by on-line association with a system and a mini-computer.
- Ensures the material nature of the points recorded in the memory, thanks to an instantaneous transfer under the eye of the plotter. The points extracted are marked for example, on a pre-established orthophotomap, which system is called *orthoguidance*.
- Performs checks on-line through looping on the different actions of the plotter, by signaling by optical, graphical or sound methods.
- Creates finally of a primary magnetic tape which is compatible with the subsequent processings, called *downstream*, of the map automation operation. This *downstream* processing system may be either a computer and large automatic drawing center (e.g., of a public community) or a system annex, but separate from the *upstream* system mentioned, and working off-line with it. The role of this *downstream* system is to classify the information following the subsequent utilization (geographic classing or classing by subject), to create drawing instruction tapes and to produce the automatic drawing. This *downstream* loop will not be analyzed in greater detail, it is not especially photogrammetric, but applies to all automatic cartography.

A block diagram showing the main general organizational functions of the short digital system is shown in Figure 2.

It is certainly true that other configurations may be conceived. They may be simpler; at the limit, these configurations amount to optica-mechanical instruments equipped with a recording of *machine coordinates* on punched tape, of low efficiency, and which have been mentioned above. Other structures may also be more elaborate culminating in *self-correcting* systems complete with typewriter, forming autonomous data acquisition and processing systems, a description of which is given next.

It should be emphasized that this type of simple or *short* system, described before is designed to feed a center of data and drawing banks; from this very fact its use is limited to the *acquisition and the pre-processing of data*. The production of several similar systems is coordinated with that of a single data bank center, which assures the processing and the drawing. But, in other instances, it is perfectly in order if, from a study of the cost-production parameter, preference is given to complete self-correcting systems, called *long* systems.

No rules are laid down as to the type of stereoplotting instrument, in any of the configurations described. The first four systems created have been adapted to "MATRA type

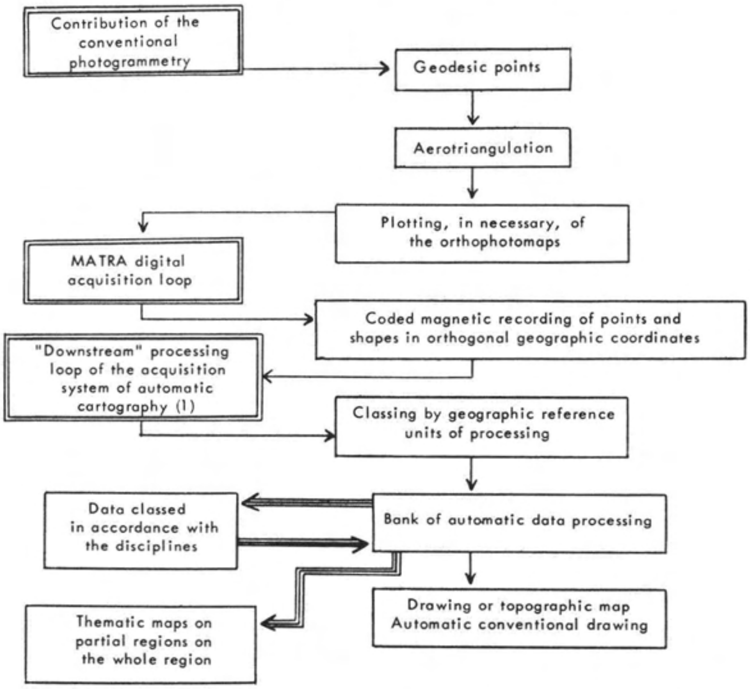


FIG. 2. General functional block diagram—sample of a "short" system.

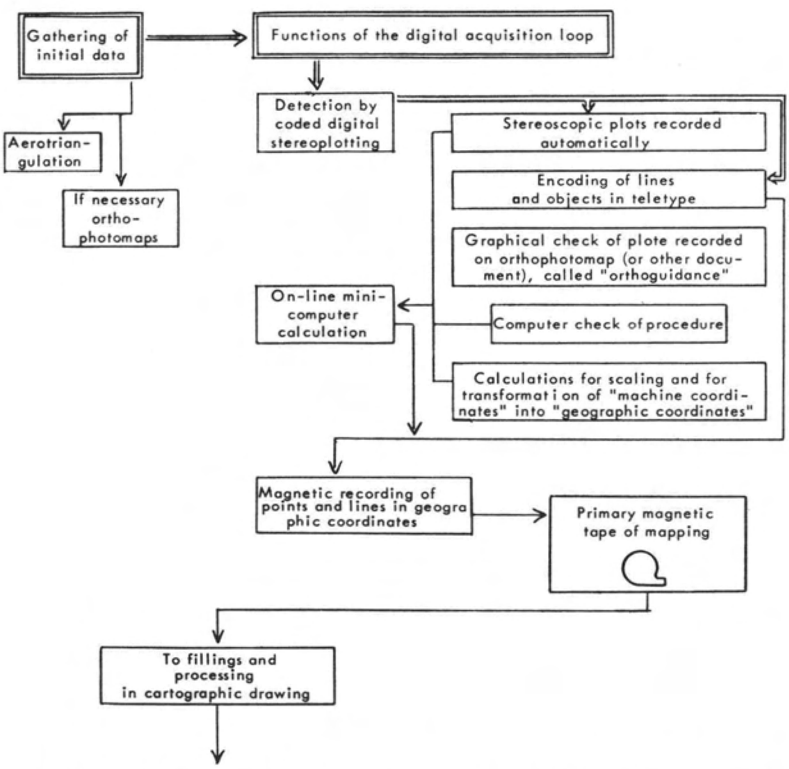
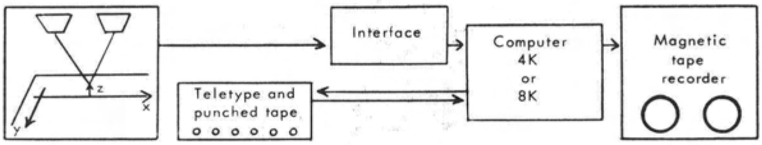


FIG. 3. Block diagram of the functions of the digital acquisition loop—sample of a "short" system.

System elements



Functions of elements

Acquisition by stereoscopic plotting. Or XY mapping on a document on a luminous table. Check of acquisition in the model by marking on a document placed on a "orthoguidance" table.	Instructions to the comptuer. Results of calculation and agreement of points. Error detection signal. Introduction of complementary data and coordinates. Digitizing and writing of the toponymy.	Coding of pulses emmitted by the detectors. Scale changing device. Display of X, Y Display of Z	Conversion of "model coordinates" into "geographic coordinates". Checks of format and of recording rules. Associations of the magnetic tape with different counters (of characters, etc.) allowing the work of the subsequent processing computer to be minimized.	Recordings compatible with the subsequent processing computer for the drawing of maps and the classing in data card fills.

FIG. 4. Block diagram of the "short" system configuration of digital acquisition (made by MATRA-SFOM).

920" projection stereopolotters. But others have been made from Wild, Zeiss and Kern optical-mechanical instruments.

A good method of choosing the type of plotting instrument is to highlight the respective merits and drawbacks of each one.

The projection plotter (Figure 5), specially fitted out, has the following good features: (a) it only requires one operator, (b) it takes advantage of the instrument's luminous table to organize, on the orthophotomap or the drawing, the acquisition program, the placing of the drawing in sheets, the toponymy, etc., and to follow directly on this table the checking of the recorded points, by *ortho-guidance* (or plano-guidance), (c) it completes the measurements of the model by recordings, if necessary in the *XY* plane (with an adapted magnifying glass), to introduce numerically in the recording, after *affine conversion*, if necessary, and (d) it uses occasionally the system for the *X*, *Y* recording of existing drawings. However, it has *drawbacks*: (a) lack of comfort for the operator, (b)limitations of model enlargement, and (c) an accuracy a little poorer than that of optical-mechanical instruments.

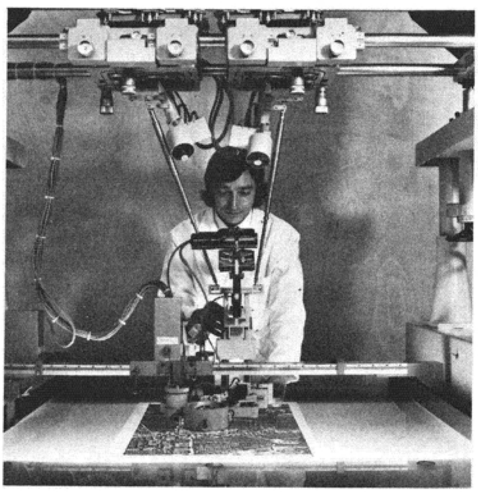


FIG. 5. A projection-type plotting instrument.

The advantages of the *optical-mechanical plotter* (Figures 6 and 7) are: (a) higher accuracy (all this greater precision may be used without any failure by the digital system); (b) offers good comfort, (c) use widespread in numerous countries, which leads it quite naturally to be considered as forming a complement to digital systems. Drawbacks of the optical-mechanical plotter are: (a) the distance at which the operator is located from the *ortho-or plano-guidance* table (but this defect may be remedied, luckily, by the addition of a television system, detecting the image at tracer level and reproducing it on a

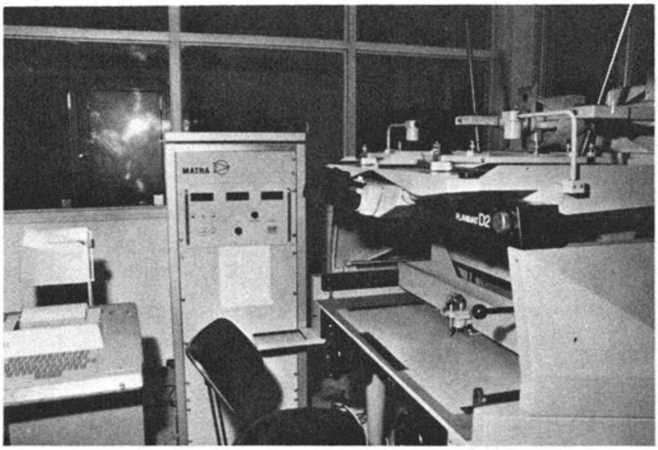


FIG. 6. An optical mechanical plotter.

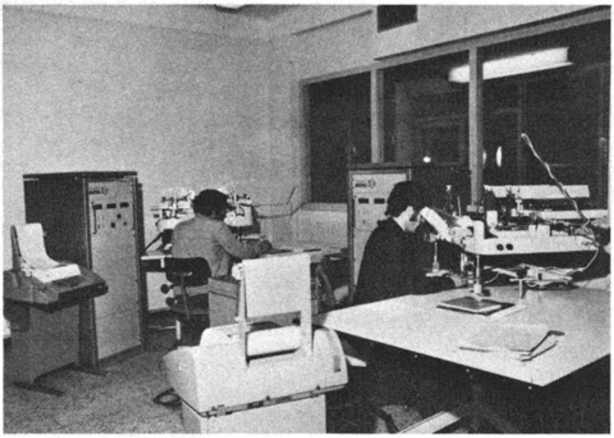


FIG. 7. Additional optical mechanical plotters.

screen in front of the operator), (b) higher cost, entailing higher capital investment. This shows that the type of plotting instrument is independent of the digital system used (and vice versa?).

Let us consider some of the details of the modifications made (for the first four units) in *short digital systems* on projection plotters.

On the instrument, a precision coordinatograph has been adapted to the table. It comprises a rotary pulse detector for each of the *X* and *Y* movements. The carriage of the mobile arm (rail of the *X* coordinate) is equipped with: a mobile screen in Z with pulse detector, provided with a stereoscopic pointer index; a pricker-pencil moved by the coordinate recording contractor, the action of which may be engaged in a variety of ways; a control by electric motor of the screen's vertical displacement; the usual accessories for these instruments, such as the *stereoimage alternator*; a retractable magnifying glass allowing *X*, *Y* acquisitions to be made in the plane of the table; and the *X*, *Y*, *Z* recording push-button.

The teletype (Figure 8) comprises a tape punch; it enables one to dialog with the computer to which it is directly connected.

The interface, with *X*, *Y*, *Z* luminous display (with pre-selection knob), allows above all the encoding of the pulses emitted by the detectors of each of the coordinates, and the assimilation by the computer of coordinate conversions. It carries: a scale changer, for reading of Z with pre-selection; and an automatic trigger on time constant, another trigger on distance constants, and a third on distance constant of *X* and *Y*.

The computer (Figure 9) has a capacity of 4K or (better still) of 8K words. Its programs, introduced rapidly by magnetic tape, are evidently specific for the type of work foreseen.

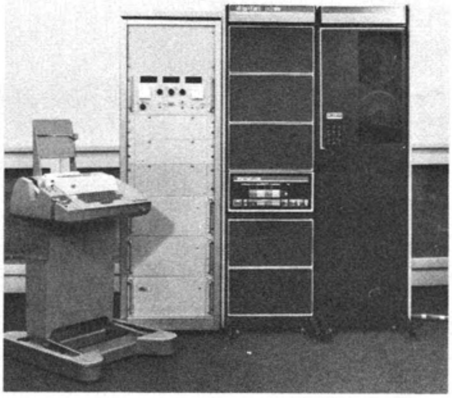


FIG. 8. A teletype station. See also Figure 10.

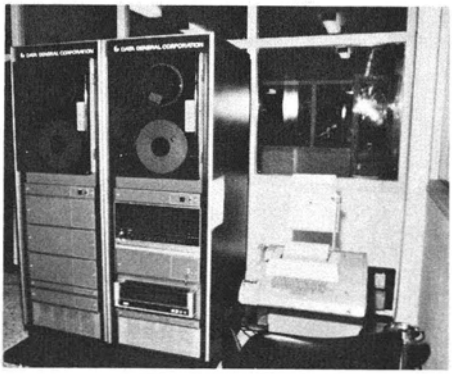


FIG. 9. Tape drives and computer.

The role assigned to it: allow the rapid scaling of the photogrammetric model with calculation and storage of the coordinate conversion parameters (which may be conform or affine); convert the *model* coordinates into *geographic* coordinates; assure the largest possible number of recording checks—order in which the instructions are introduced (the filing of data by map edition sheet differs, in actual fact, from the filing of data extracted pair by pair); check of the omissions in the drawing of filing instructions; check of obvious incompatibilities, etc. . .These checks are interspersed with response instructions given to the teletype of the operator. This set-up relieves the data bank computation center and above all renders this band autonomous of the "data acquisition systems".

Already, a large number of programs have been compiled, e.g., for stereophotogrammetric plotting of urban maps, for tracing contours, for topographic surveys of urban volumes on a very large scale, and the restitution of their perspectives of the most varied tapes, and for the integration of old maps in a photogrammetric out-line, etc.

Of course, each specific regulation of a type of survey leads to modifications of acquisition and computer programs. This gives a good idea of the extreme flexibility and the modularity of the system.

The low cost of the system is assured by its high productivity rating. The number of points carefully processed in an hour on the *short digital system*, described above, varies from 280 to 400, depending on the geographic difficulties and the operators. Thus, the cost of a point is less than a quarter of the cost resulting from the best recording devices most frequently used. But in addition to this interesting feature, there is the economy brought about by the simultaneous creation of *data card files*, or banks, sorted by the computer of the *downstream* operating center, and also that of the automatic drawing which concludes the operations.

DIGITAL DATA ACQUISITION SYSTEMS OF THE AUTONOMOUS LONG SELF-CORRECTING TYPE

In a general manner, the acquisition systems such as those of the short system already described, as well as those of self-correcting systems of which mention will be made further on, have an autonomous structure which is of general application.

This signifies, in particular, that their configuration may be transposed in all the systems of automatic cartography. This is true for example for systems based on the utilization of data derived directly from topometric surveys on the ground. This applies also to acquisitions on the X, Y digitizing table of elements of a map already drawn.

This must be so, in actual fact, to allow the adaptation to all the cases of cartographic work organization. One may, for example, mention a controversial question, i.e., is it, or is it not, preferable to perform either (a) a direct digital acquisition in the photogrammetric model, completed or updated by a system of terminal able to dialog with the computer, or (b) a conventional graphical restitution completed by data gathered on the ground, and then digitized on the X, Y table.

The answer depends both on the traditional habits of the organization performing the work, and on the development and the utilization facility of the dialoging terminals, for the corrections and updatings. This last point is finally linked to the performance of programs of organizing cartographic files. Present trends seem to indicate that the first solution will be the course followed in the future. Now, the *long self-correcting* system meets precisely this conversational require-

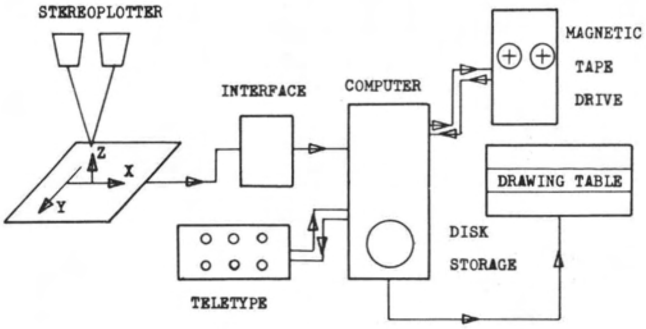


FIG. 10. Block diagram of the self-correcting system.

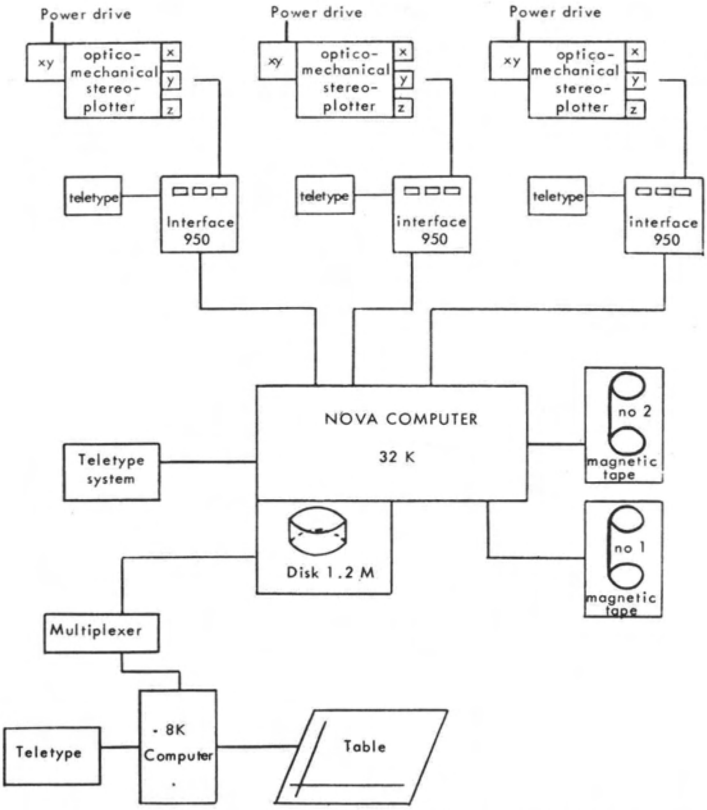


FIG. 11. Block diagram of a system with a single on-line drafting machine for "intermediate" and "final" drawing.

ment of checking, correction and updating.

The self-correcting system, designed by the same specialist of systems as the "*short digital systems*" is intended to render the acquisition system independent of the subsequent data processing system. It assures that the primary magnetic tape shows neither errors nor omissions, thanks to a graphical output. It should also be stated that the efficiency with which this action is performed may be made high enough for this output to create the final drawing. The role of the *downstream* processing center, thus freed is in this instance only to perform the classifications in selective card files intended to meet the general and subsequent requirements. In addition, this system assures the uniqueness of stored coordinate values for the same point belonging to several different and associated classifications. A block diagram of the *self-correcting system* is indicated in Figure 10.

This system is therefore more complex than the *short digital system* because one must add, firstly, a drawing table and its associated program and, secondly, a desk unit to perform the corrections and updatings. It is also equipped with a proximity search software to reveal the identical points and to calculate mean values.

Optical Mechanical Plotters

One coherent data acquisition and automatic drawing system groups three assemblies of digital systems associated with optical mechanical stereoplotters. This forms a significant example of the modularity of these systems allowing them to be adapted to the specific requirements of a particular organization. It consists of a MATRA system placed in service in a large national geographic center.

This ensemble comprises a groupe of three acquisition stations, on Zeiss and Kern instruments (Figures 11 and 12), processed in time-sharing by a Nova computer of 32 K central memory, coupled to a disk store of 1,200,000 words of memory, a teletype system and two IBM compatible magnetic tape drives.

Each of the three data acquisition stations comprises three optical encoders sensitive to 1/100th mm, a MATRA interface comprising the display of the X, Y coordinates a multiplication factor of the Z recordings, and a variety of devices for the recording of the points, the automatic incrementation of a point number and finally a hard copy output teletype, to dialog with the computer. This system has the *following working program*: acquisition chain control; access blocking to give priority to *teletype system*; acquisition checking; image point setting and various corresponding checks; calculation of the geographic coordinates and various checks.

The principle of operation is as follows: each station records its data in the location assigned to it in the disk; after checking, the transfer is performed without any preferential order of the disk on the tape; outside the acquisition periods, the data are rewritten on the second magnetic tape after *sorting on a disk* (tape-to-tape work); this new tape is the final tape arranged by map sections—it then serves to establish the control tape of the drawing instrument.

Checks and corrections have been carefully studied. In spite of the large number of checks performed by the acquisition program, the very exactness of the acquisition has not yet been tested, as it should be before the final drawing, while the photogrammetric pair of images is still in position. These checks may be executed on a display console, but it has been thought preferable to use a small drawing table to perform these

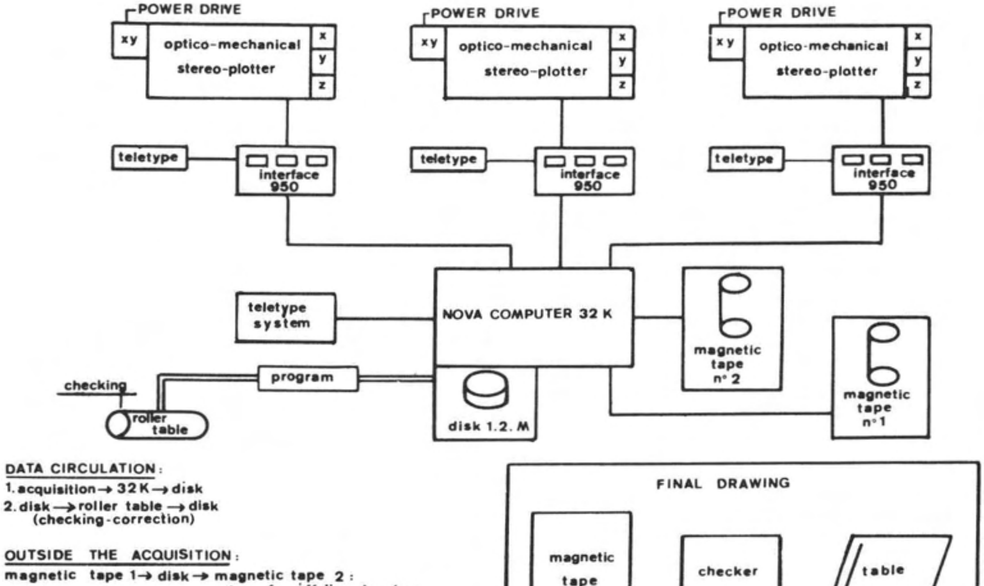


FIG. 12. An alternate version of Figure 11 consists of placing the drawing table in an area different from that of the data-acquisition plotters.

intermediate drawings (every 500 points, for example). The acquisition errors discovered may next be directly corrected on a disk. Of course, the *final high-class drawing*, section by section, is established in its integrity off-line. This arrangement is shown in the diagram shown in Figure 11.

Another version consists in only using a single on-line drawing table (linked to the 32 K computer, completed with the multiplexer of an 8 K computer with teletype) which performs its work without interfering with data acquisition. The final drawing is then drafted outside the acquisition area with the same equipment and the 32K computer. The block diagram of this set-up is given in Figure 12.

Future of Computer-Processed Numerical Photogrammetry

What developments may one expect, in the short term? In the first place, it is expected that existing stereoplotters, projection or optical-mechanical, will be equipped with digital acquisition systems. Grouping plotters in series, working in time-sharing, will be greatly appreciated. This is, moreover, a development which is already underway. It is also well to stress that such systems are not, as one might be led to believe, created by associating hardware units but, on the contrary, involve compatibility and software problems which are both arduous and difficult to resolve, even for engineers specializing in the creation of such systems.

In the meantime, one may expect first of all that developments will take place in the equipment of digital systems on existing anlog instruments and probably, self-correcting and tracing autonomous systems. Next in this perspective, one may expect that the reliable analytical plotters will come into service; in fact, this automation channel should open up an industrial activity field for these instruments. One must admit that such an opening was not clearly evident at the time of the advent of the first analytical units.

In the long term, it is not unreasonable to believe in an extension of complete digital systems, but supported by data deriving from reliable analytical plotters and often grouped in series.

In conclusion, it is quite evident that an increase in cartography productivity will be achieved through automation. Inasmuch as the greater part of the production of drawings and maps is photogrammetric, it follows that automatic photogrammetric cartography is henceforth a fundamental method.

It is perhaps worthwhile considering what concerns men as such. Emphasis must be laid on the development of the technological qualifications of the technicians responsible for the systems and the plotters; this factor, i.e., better skills, is fundamental—it concerns elementary statistics, programming and electronics.

It is true that all countries now possess certain details, drawn from experience, in these fields to which those interested may refer if they so wish. This point should be well-known, and stressed, to allow conventional photogrammetry to be placed in its correct historical setting, and a new chapter opened, more flexible, more adaptable, because it is more modular.

Errata

Several printing errors were included in the article, "A Theorem in Least Squares," by H. S. Williams in the November 1972 issue of *Photogrammetric Engineering*. In Equation 8 on page 1128, the fourth term should be

$$A_1{}^t W_1 f_1$$

and in the last equation on the same page, the first term should be

$$w_2 A_2 Q_1{}^{-1} .$$

The second term of the equation at the top of page 1129, a subscript *1* was omitted from the last element:

$$Q^{-1} A_2{}^t w_2 A_2 Q_1{}^{-1} .$$

The last term on the second line beneath Equation 13 should be an X instead of Q:

$$A_2 Q^{-1} (Q - Q_1) \Delta X'^{\,*} .$$

In the second term of the second equation beneath Equation 15, the asterisk after D should be deleted:

$$Q^{-1} A_2{}^t (A_2 \Delta X' + f_2) .$$

In the third line from the bottom of the same page, a plus sign should appear instead of a minus:

$$(A \cdot \Delta X^* + f) .$$

and the last term of Equation 17 should be

$$-\Delta X^{*t} Q_1 \cdot \Delta X^* .$$

On page 1130, the last term before Equation 19 should be

$$+ X'^{\,*t} Q_1 \cdot \Delta X'^* .$$

The Editor regrets these mistakes.