ations and the reverse task of reading automatically the corresponding numerical values on the scales. No doubt the solution of this problem is of paramount importance in connection with the design of a new stereocomparator. Nevertheless, it would seem that satisfactory solutions may be expected for the problems of recording, computing and printing with necessary reliability and speed, since these problems exist in many research and development projects, having even higher requirements. The actual problem in an analytical approach, it is felt, is the economical solution of the measuring process on the stereocomparator. The measuring of plate coordinates of individual points must be carried out without the benefit of a preceding relative orientation, and, therefore, in the general case, specific x and y parallaxes must be eliminated for each individual point during the process of measuring the corresponding plate coordinates. In other words, by scanning over the field common to the two photographs under consideration, the continuity of the stereoscopic sensation is not maintained but must be recovered from point to point. All the necessary means for establishing maximum stereoscopic effect can be applied using image reversing prisms and panchratic systems in both light trains. To what extent advantages inherent in an analytical method can be utilized in practice will therefore depend chiefly on the ingenuity of the designer to combine the well-known basic principles of a stereocomparator with such operational features as will provide an economical observational technique.

PHOTOGRAMMETRIC APPLICATIONS OF SMALL CAPACITY ELECTRONIC COMPUTERS*

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Abstract

The operational features, capabilities and limitations of small capacity computers such as the IBM 602 A and its allied equipment are described by analogy to hand computing methods. An evaluation of the potentialities of the equipment shows that it is limited to problems where the same operation must be performed numerous times with variation of some parameters. The computation of graphs of stereo-model deformations is used to illustrate the type of problem suitable for such equipment. Economic considerations make it apparent that a large amount of work is required in order to make the installation of such equipment worthwhile.

1. Introduction

IF ANY three devices are symbolic of modern technology, they are probably flying saucers, atom bombs, and electronic computers. The amount of misinformation prevalent on these topics is appalling. Most of this misinformation comes from popular articles which tend to be highly sensational in approach. In particular, the reference to computers as "giant electronic brains" causes many people to regard them with an awe which is not otherwise deserved. In addition, the practitioners of electronic computing have developed their own jargon, and delight in throwing around terms like digitizer, readout, nines complement counter, crossfooting, etc., which for the most part leave the average man no wiser than he was before he heard them. One lamentable result of this is

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that men who should be using these machines for practical problems still regard them as abstruse arrays of flashing lights which they see on television on election nights.

Without detracting at all from the ingenuity of computer designers, or from the mathematical sophistication of many of the people who use them, it is possible to describe electronic computing in terms of its operations, capabilities and limitations.

The Mapping and Charting Research Laboratory at The Ohio State University uses a small IBM calculator and its allied equipment as a general purpose digital computer serving all departments in the laboratory. The basic unit is the 602-A punched card calculator (Figure 1). This is actually an electromagnetic rather than an electronic computer, but the principles of operation are essentially the same.

2. Principles of Operation

Fundamentally, the computing machine is composed of four interacting units: (a) Input-output, (b) Storage, (c) Arithmetic, and (d) Control. The relations between these units are indicated in Figure 2. The solution of a problem on such a machine is closely parallel to the operations which would be performed on a conventional desk calculator.

The first operation is to analyze the problem into a series of steps which can be performed by the machine. It is necessary to determine the sequence in which operations are to be performed, as well as the order in which the factors and intermediate results are to be used in this sequence. This is programming. For a desk machine it would be done by listing the operations on a sheet of paper or designing a computing form. For the automatic computer it is done by wiring the control panel. If the machine has a "brain" at all, this control panel is it. Figure 3 is a panel designed for taking the vector product of two eight digit three dimensional vectors. Each wire on the control panel carries an instruction or a digit between the units of the machine. Although the final board looks fairly formidable, it is built up step-by-step without too much difficulty.

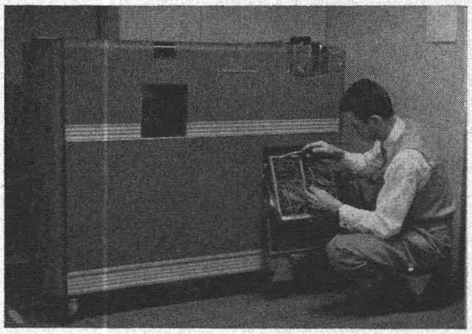

Fig. 1. The IBM Model 602-A calculating machine. The operator is installing the control panel which directs the sequence of operations within the machine.

The second operation is to insert the given data. On a desk machine some numbers would be stored on paper, others entered directly in the machine by the keyboard buttons. For the automatic computer all data are punched on cards (Figure 4).* Each column on the card can represent one digit, whose value is determined by the position of the punch mark. These cards are placed in the machine and the input brushes read the digits by electrical contact through the punched holes. The control panel then directs the input to send the numbers either to a storage unit for future use, or to the arithmetic unit for immediate use.

The next operation is actual calculation. On a desk machine this would be

* The illustration which was received was enlarged about 43% to make it possible to read the captions.—*Editor*

done by depressing the appropriate control button. The control panel of the automatic computer directs the arithmetic unit to add, subtract, multiply or divide. Just as on the desk machine, these are the only operations which can be performed. Transcendental functions (logarithms, trigonometric functions, exponentials, etc.) are generated either from a series or polynomial expansion, or are taken from tables punched on cards.

The next operation is to read out the results. From the desk machine, the operator may copy down the result on paper, or he may reenter it on the keyboard for another calculation. In the automatic computer, the control unit directs the arithmetic unit to send the result to storage where it may be kept for subsequent use, or a second signal may direct the storage unit to send the number to output where it would be punched on the card. If this is a final result, the card may be sent to the tabulator for reproduction on paper; otherwise the card serves as a form of external storage. Frequently it is convenient to change the order in which cards are stacked, either before continuing with the calculation or before tabulating. The sorting machine fulfills this function.

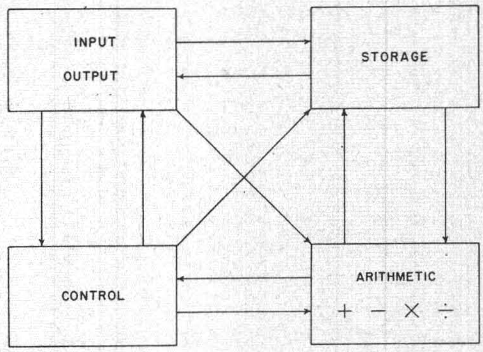

FIG. 2. Diagram of digital computer. The arrows represent the flow of instructions and numbers between the units of the machine.

As a simple example of how these operations are performed by the machine, consider an elementary multiplication.

$$5{,}280 \times 12 = 63{,}360.$$

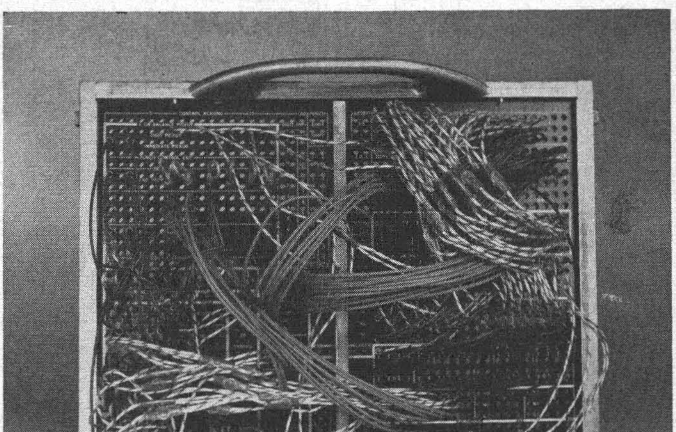

FIG. 3. Control panel for vector product. The wires on the left side of the board control the sequence of operations. Those on the right side provide the necessary paths for the digits to travel between the various units within the computer.

The two factors are punched on the card (Figure 4), the multiplicand in the first four columns, the multiplier in the 9th and 10th columns, and the result will be expected in columns 13 through 18.

The control panel must now be wired (Figure 5). Essentially the left half of the board controls the program; the right half provides the paths for digits between the various units within the machine. This board is built up as follows:

a. On the read cycle two wires (*a*) on the left tell storage units #1 and #2 to read from the card. The group of four wires (*b*) on the right provides a path from the input brushes of the first four columns on the card into storage #2. Two wires (*c*) provide a path from card columns 9 and 10 to storage #1.

The computation will be performed in counter #1, and the short jumper (*d*) is required to set up this counter for operation.

b. On the first program cycle the wire (*e*) tells storage #2 to read out, and the wire (*f*) tells counter #1 to read in. The wires (*g*) on the right side provide a path for the four digit multiplicand between storage #2 exit and counter #1 entry. At the same time the single wire (*h*) tells the machine to multiply by whatever factor is in storage #1. The answer is now in counter #1.

c. The second program cycle takes the answer from counter #1 and punches it on the card. The wire (*i*) tells counter #1 to read out the answer and wire (*j*) tells storage #6 to read it in. The wires (*k*) provide the necessary path between counter #1 exit and storage #6 entry. A jumper (1) tells counter #1 to reset to

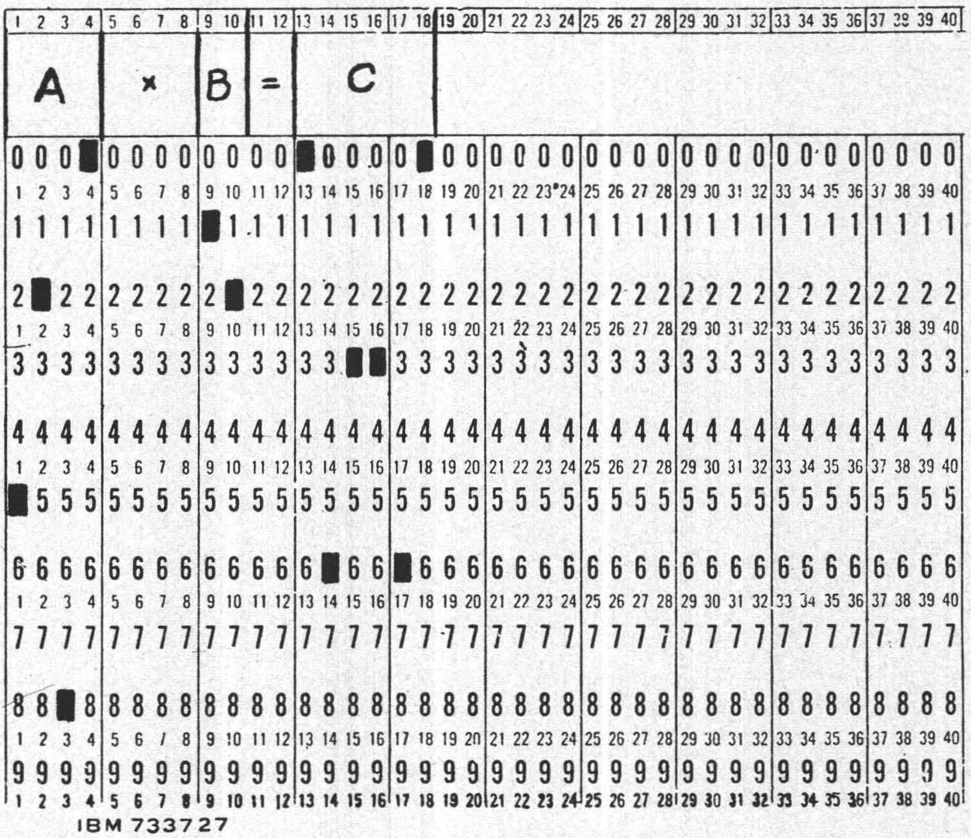

FIG. 4. Punched card for inserting data in the machine and receiving the computed result. Each column can represent one digit whose value is determined by the position of the punched hole. Only part of the card is illustrated. The actual card has 80 columns.

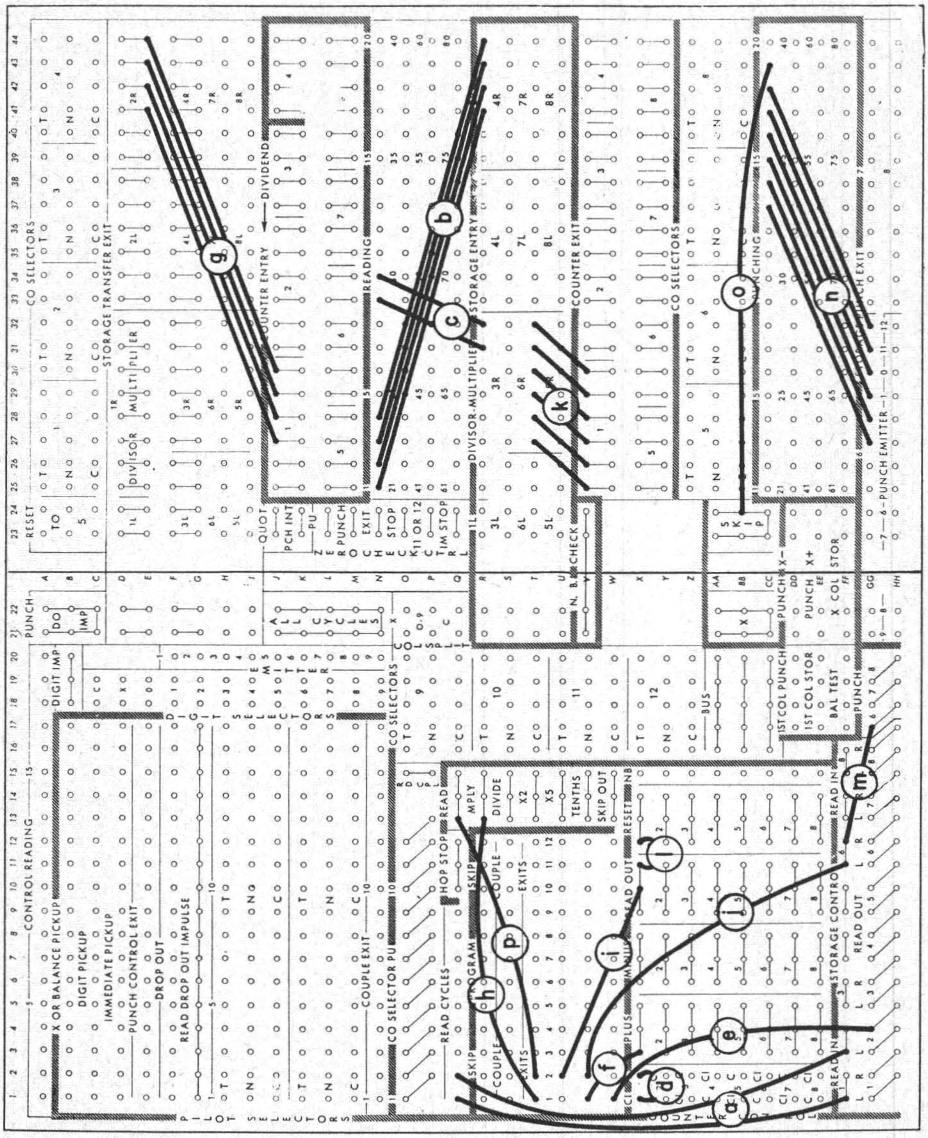

FIG. 5. Control panel for multiplying one four digit number by a two digit number.

zero. The jumper (*m*) tells the output to punch the number from storage #6 onto the card. The wires (*n*) provide the path for the six digit answer from storage #6 punch exit to columns 13 through 18 on the card. The wire (*o*) tells the machine when it is through punching and ready to read. Finally wire (*p*) tells the machine to read the next card, and the entire operation may begin again.

The result of this computation appears in the six columns 13 through 18 on the card (Figure 4). Six digits were set up, but only five were necessary. Therefore the digit in column 13 is 0 and the answer 63,360 is read in the remaining five columns.

Obviously it would be foolish to go through this amount of work merely to multiply these two numbers. However if there were several hundred, or better yet several thousand of four digit numbers to be multiplied by two digit numbers, then machine computation becomes practical. This is the primary fact to be considered in judging the suitability of a problem for solution by most automatic computers. There must be a demand for repeating the same operation a large number of times with no changes other than variation of some of the parameters.

3. Photogrammetric Applications

As a simple example of a suitable photogrammetric application for electronic computation, consider the problem of determining the theoretical standard error of elevation measurements in a stereo model formed from convergent photographs. The formulas for this are:

$$m_h = \mu\sqrt{Q_{dhdh}}$$

in which

$$\begin{aligned} Q_{dhdh} = {} & \frac{(x-b)^2h^2}{2b^2d^2} + \frac{y^2}{b^2}\{h\cos\phi_2 + (x-b)\sin\phi_2\}^2\left(\frac{2\cos^2\phi_2}{3b^2} + \frac{3h^2\sin^2\phi_2}{4d^4}\right) \\ & + \left[\frac{h^2}{b} + \frac{(x-b)^2}{b}\right]^2\frac{h^2}{b^2d^2} \\ & + \frac{y^2}{b^2}\{(x-b)\cos\phi_2 - h\sin\phi_2\}^2\left(\frac{3h^2\cos^2\phi_2}{4d_4} + \frac{2\sin^2\phi_2}{3b^2}\right) \\ & + \frac{(x-b)}{b}\left[\frac{h^2}{b} + \frac{(x-b)^2}{b}\right]\frac{h^2}{bd^2} \\ & + \frac{2y^2}{b^2}\{h\cos\phi_2 + (x-b)\sin\phi_2\}\{(x-b)\cos\phi_2 - h\sin\phi_2\} \\ & \cdot\left(\frac{3h^2}{8d^4} - \frac{1}{3b^2}\right)\sin^2\phi_2. \end{aligned}$$

In these expressions μ is the standard error of y-parallax observation, x and y are the coordinates of points in the projection plane, b is the projected image of the airbase, d is the distance from the airbase to the points used for relative orientation, h is the projection distance, and ϕ is the inclination of the camera axis.†

It is desired to evaluate this standard error at sufficient points (x, y) so that contour lines of equal standard error may be drawn over the model. Furthermore it is desired to make this evaluation for several different values of base-height ratio and ϕ. If this were to be done on a desk computer, it would be necessary to hold the number of points to a minimum. Even so there would be several hundred evaluations to perform. It therefore becomes a problem suitable for automatic computation. Once the necessary programming has been done, it is no problem to increase the number of points per graph or the number of combinations of the fixed parameters, b, h, d, ϕ.

† Example from: Hallert, Bertil, "Basic Factors Limiting the Accuracy of Mapping and Aerotriangulation by Photogrammetric Procedures." *Sixth Interim Technical Report*, period 1 April 1954 through 30 June 1954. Mapping and Charting Research Laboratory, The Ohio State University, Columbus, Ohio. Contract No. DA-44-009 Eng. 1490, Project No. 8-35-03-018, placed by Engineer Research and Development Laboratories, Fort Belvoir, Virginia.

There are essentially two philosophies of computing: series and parallel, and the choice is usually forced on the user by the structure of his machine. In series computation this expression would be completely evaluated for each set of values as one continuous operation; in parallel computation each term, or perhaps only part of a term, would be evaluated for all sets of parameters on one run. In some cases these intermediate results may be added as they are found, while in others they may be punched on cards and the final summing postponed until the last operation. In general the series computer is more adaptable, and all the very large computers are built on this pattern. However it is one of the facts of life that parallel machines are easier and cheaper to build, and most small machines, including the 602-A, compute in this fashion. The 602-A is limited to about twelve program steps on one pass of the cards while the CPC (Card Programmed Calculator) as an example of a series machine, can take a program of unlimited length.

This problem would therefore be solved on the 602-A by breaking each term into component calculations which could be solved in one pass of the cards. This term would be evaluated for all values of x, y, b, d, h, and ϕ, and the results punched on cards. The next term would be handled in the same way, until all terms had been computed for all values of the parameters. The cards would then be run through the sorting machine to separate them into the proper groups for summing, and this sum would then be taken as the last computing step. A final pass through the sorter might arrange the cards in order of increasing x and y for each set of values of b, h, d, and ϕ. Running the cards through the tabulator would then present the data in convenient form for the draftsman.

The graph shown in Figure 6 shows the result for $\phi = 20°$, $b = 1.23h$, $d = 0.64h$ and $\mu = 1$.

4. Economic Considerations

It is necessary to say a few words about the economics of computer operations. The rental for an installation, such as that at the Mapping and Charting Research Laboratory, is about \$1,000 per month. A full time mathematician at about \$600 and an operator at about \$350 are required to service the machines. The total expenditure is thus in the neighborhood of \$2,000 a month. It is a little difficult to state a ratio between what the machine can do and what can be done on a desk machine, since this depends largely on the type of problems to be handled. When working at full efficiency the machine will do in two days what a good operator can do in a month. But down time and changeover cut into this.

Taking all these factors into consideration, the machine and two people can do the work of ten to twelve full time desk computer operators at a cost equal to the salary of four operators. An organization ought to have, therefore, sufficient work to keep five full

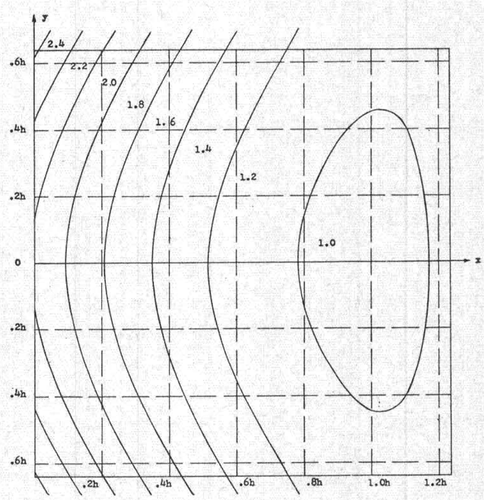

Fig. 6. Graph of standard error in elevation for a stereo model formed from convergent photographs. The standard error is computed at each intersection of the grid and contour lines of equal error are drawn.

time computers busy, before electronic computing would be profitable. Not many private operations will have so large a demand. But it is still possible for those whose requirements do not justify installing their own machines to gain the advantages of electronic calculation. Most government agencies have, or can arrange, access to machines in other departments. Many universities now operate computing laboratories and the number and scope of these is rapidly increasing. There also exist a number of commercial concerns where computing time can be purchased.

5. Conclusions

The primary advantage of electronic computing is that it permits the solution of problems whose scope would make them unreasonable or impossible on desk machines. A second advantage is speed since even the slowest machines are several times faster than the best operator on a desk machine. The third advantage is accuracy. Although electronic computers do make random errors these are easily checked and corrected, whereas in most desk machine operations, errors may only be found by repeating the whole calculation with no guarantee that the second attempt is any better than the first. Furthermore the ease with which results can be presented in the most convenient form is a considerable advantage.

The big disadvantage of electronic calculation on parallel machines is the fact that they are only suitable for repetitive work. A one shot computation, regardless of its complexity, might just as well be performed on a desk machine. However this is not necessarily true of computation on series machines. Another point to be considered is that machine costs continue whether they are operating or not, and they require personnel with skills which may not contribute directly to the work in an organization.

Automatic computation will not bring on the millennium but it will certainly do much to expedite the handling of large masses of data.

It is by no means necessary nor even expedient that professional photogrammetrists become skilled practitioners of electronic computation. But it is highly desirable that they become cognizant of the capabilities and limitations of these machines, so that they may be aware of where they can use this important new tool, and may design their problems accordingly. The practical questions of programming and machine operation are far better left in the hands of those who have made electronic computing their profession.

The author expresses his appreciation to Mr. Robert A. Mosier, mathematician in charge of the computing section at the Mapping and Charting Research Laboratory, who gave valuable assistance in the technical aspects of this paper.

MEDIUM-CAPACITY ELECTRONIC COMPUTERS IN PHOTOGRAMMETRY*

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IN DISCUSSING the subject of this paper the author is aware that there is no well-defined or accepted concept of exactly what is meant by medium-capacity electronic computers. The factors which must be stipulated would include the rate at which the computer performs the mathematical operations, the storage

* This paper is a part of the Symposium on Computing Trends in Photogrammetry held on March 7, 1955 during the Society's Annual Meeting.