Analytical Plotter in Photogrammetric Production Line

U. V. HELAVA,
Photogrammetric Research Section,
Division of Applied Physics,
National Research Council, Ottawa

ABSTRACT: *The analytical plotter is presented in this paper in general terms. Its principles and various advantages are briefly described. Particular attention is paid to the new possibilities offered by the analytical plotter to improve the performance in photogrammetry. It is pointed out that in small-scale mapping an integrated system of analytical methods may lead to a considerable saving of time. The time normally spent for relative and absolute orientations may be almost entirely saved. In large-scale mapping a total correction for the entire system of photogrammetric mapping may be determined by a calibration over a test area. This is one of the most promising possibilities to increase the accuracy of photogrammetry when the utmost is needed in this respect. For all these improvements the analytical plotter is the key factor necessary for progress.*

INTRODUCTION

THERE is rapid and vigorous progress going on in all technological fields, and photogrammetry is no exception to this general trend. In the development of photogrammetric methods and techniques the influence of electronics and data processing methods is particularly strong. There is already in existence a wide variety of electronic coordinate printers, photographic printers and analytical methods that use electronic digital computers as well as the first working models of electronic rectifiers and automatic contour followers. The first designs for an analytical plotter (1) using electronic computations are already in existence. To assess the importance of these new developments and to make evident their significance to the future of photogrammetry is one of the most urgent problems facing photogrammetrists today. In this paper some thoughts and ideas as to the potential possibilities of an analytical plotter will be presented. One aim is to illustrate in general terms the possibilities that the analytical plotter offers to an improved performance in photogrammetry, and another is to point out the importance of the analytical plotter to efficient photogrammetric production.

First a few words on what is meant by the words "improved performance." First of all they mean better economy: the same quality of work for lesser costs, or better quality for the same costs. Secondly, an improved performance means that under the same conditions a higher degree of accuracy may be achieved. These two meanings are obvious. Less obvious, but not less important, are the advantages obtainable through increased speed and the opportunity to better organize the work. Production capacity per time-unit, training and supervision problems often hinge on these aspects of photogrammetric mapping; their importance should not be underestimated.

When considering all these aspects of improved performance the advantages offered by analytical methods become increasingly attractive, particularly if an integrated system of analytical methods is envisaged. Such a system should be designed to utilize all of the potential advantages obtainable by the application of analytical and data processing methods, and should cover the entire chain of operations necessary in photogrammetric process, from photographs to the final map. There are many links in such a chain, and progress is made step by step by the creation and improvement of individual links. It seems that at the present time enough important links are already so far advanced in their development that the outline of the entire chain is beginning to emerge. In any further development this outline should be kept firmly in mind and it is from this standpoint—which the author believes to be one of the important links—that the analytical plotter will be discussed in the following pages.

The Principle of Present Plotters

A study of present photogrammetric plotters reveals that, before considerable improvements in performance can be expected, drastic fundamental changes are needed in the principle on which the functioning and construction of our present instruments is based. We may call the fundamental idea of these instruments the simulation principle. In general terms it works as follows: Physical projection—optical, mechanical, or combined—is used to reconstruct bundles of projecting rays. The bundles are brought to the required orientation by introducing physical rotations and translations. The end result is obtained by observing and measuring dimensions from a "model" formed by the intersection of corresponding rays. The assumption is that the "model" is an exact copy of the photographed object in a certain scale. In general this assumption is correct. However, when we require results of the highest accuracy we find that several corrections are needed to get a perfect model.

The simulation principle prevents us from introducing in a practical way certain corrections that are known and could be taken into account. We will also note that we cannot use to the full extent the advantages of redundant observations to increase the accuracy of orientation. From a more practical point of view additional drawbacks become evident; the instruments require frequent adjustments and calibration; they are bulky, heavy and inflexible in use. In the case of some models, even the change of focal-length causes difficulties. Only one plotter—and even that one is not on the market as yet—is capable of plotting from super wide-angle photographs. Many other minor drawbacks could be listed. They all support the conclusion that fundamental changes are needed before considerable improvements may be expected.

The Principle of Analytical Plotter

The analytical plotter is a photogrammetric instrument which is based on an entirely different principle. It presents several advantages over the simulation principle. In the analytical plotter a mathematical projection is used, the photographs are not projected by conventional, optical or mechanical means. Rather, the position is computed in which an image-point would appear if an ideal central projection had taken place. In addition, deviations from the ideal case, such as those caused by lens distortion, atmospheric refraction, film shrinkage etc., are also derived. The photographs are then shifted in their plane to bring the image point to the correct computed position.

The plotter has two main parts: the viewing-measuring device and the computer. These two parts are interconnected to form a kind of feedback system. The xy coordinates from the viewing-measuring device and a computing factor equivalent to z are used as an input to the computer. Using this input data and a number of predetermined quantities equivalent to the orientation elements, distortion characteristics etc., the computer derives the necessary corrections. These are executed by a servo system which shifts the photographs independently in their plane by the computed amounts. The observer which may be a human operator or a mechanical device—such as the automatic scanning correlator (2)—may then decide what changes should be made in the input coordinates to obtain the required result.

Advantages of an Analytical Plotter

The new principle opens possibilities which were not found in the simulator principle. It allows us to include corrections for any number of known systematic errors. Thus, atmospheric refraction, earth's curvature etc.. may be taken into account. Even experimentally determined corrections can be introduced by employing special techniques. Such corrections as those for camera inclinations and terrain elevation differences may be regarded as members of the set of corrections to be introduced. A high level of accuracy may be maintained throughout the computations, and the result is affected mainly by observation errors and inaccuracies of the mechanical parts. However, the last mentioned source of errors is less critical than in the case of the simulator type instruments, due to the very simple construction and small size of the mechanical part. In addition, if the mechanical errors are systematic their effects can be compensated by including appropriate corrections.

The new principle also has the advantage of versatility. For example, the focal-lengths may be varied over a wide range, and different sizes of photographs may be plotted without difficulty. Use of wide-angle or super wide-angle photographs does not present any constructional problems. In addition, distortion characteristics of different types of lenses, even individual lenses, can easily be taken into account.

Another important advantage of the analytical plotter is that it lends itself well to automation. This is due to many reasons, one of the most important being that it is not necessary to introduce real physical inclinations of projectors to perform relative and absolute orientations. Another is that its principle allows computers of extensive complexity to be used. Calculations involved in numerical relative and absolute orientation, and possible other functionings, can be performed by the main computer or by built-in auxiliary computers. The limit is set by economical rather than technical factors.

The most interesting problem in applying the proposed principle is that of resolving the difficulties involved in the computations. Several possibilities are offered by modern technology. Digital computations can be performed with great speed, and analog computers can solve complicated equations continuously and still more quickly—in fact, almost instantaneously. Both methods have weighty advantages, such as the practically unlimited accuracy of digital computation and the great speed of the analog method. As a result of the investigations carried out in the National Research Council of Canada it has been established that there is undoubted foundation for the employment of either one of the above mentioned methods. For the most flexible and versatile solution, however, a hybrid of digital and analog computers seems to be the most advantageous answer to the computer problem.

The Analytical Plotter in Photogrammetric Production

To view clearly the position of the analytical plotter in the whole system of mapping operations we should study the different steps involved in map-making by photogrammetric procedures. For this purpose we will use the following divisions:

(1) Aerial photography
(2) Control-extension using aerial triangulation
(3) Plotting

The *first step* is the one during which the basic data are collected and recorded. It fixes permanently the geometric relations and conditions on which later processing must be based. The series of aerial photographs which is the result of this step is often considered as a series of images produced by a perfect central projection. This assumption, of course, is very nearly correct and as such, fully acceptable and useful for many purposes. However, in practice there are always deviations from the theoretical situation. The aerial photographs are actually produced by a process that is a complicated combination of many physical phenomena. The effects of many of them are well known and to some degree or another are taken into account in photogrammetric operations. Certain other effects are less well known, or sometimes unknown, and in consequence less often or never accounted for. Therefore, when processing the data as recorded in aerial photographs, it is better to base it on the assumption of a general transformation of which the strict central-projection is a useful approximation only. The principle of the analytical plotter enables the photogrammetrist to accept and utilize this more general approach.

The *second step* is one where analytical aerial triangulation methods may be used. As is well known, these methods are based on the measurement of photographic-coordinates using a special instrument called a stereocomparator. The ground-coordinates are obtained by computations performed by an electronic digital computer. During this process any number of corrections may be included. This is in accord with the requirement stressed in the previous paragraph. In this connection the analytical plotter may possess one of its advantages, since it can serve also as a stereocomparator. However, from the point of view of an integrated analytical system the following aspect is more important. It is related to the further processing of the results of an analytical triangulation.

The principal efforts devoted to the development of analytical triangulation methods have been focussed to the actual bridging procedure. However, it may be envisaged that the adjustment of triangulated strips may be performed equally well analytically. Actually, considerable work has already gone on towards this end. In this connection one further thought occurs. The adjustment should be extended in such a way, that it will result in the *adjusted orientation elements and coordinates of air stations* being obtained. These may be recorded in a suitable way and may be used to advantage, as will be outlined in a later paragraph.

The *third category* is the domain in which the analytical plotter obviously will find its widest use. We will itemize these into its two main usages. First, its employment in connection with the mass production of maps in a relatively small-scale. Second, its use in large-scale plotting where independent models are mainly used. In these two cases slightly different aspects are significant. Therefore we will consider them separately.

The automation of photogrammetric operations will probably first take place in the mass production of small-scale maps. This is the field where automation is of greater economic significance. Various steps may be considered from the point-of-view of automation possibilities: the setting of photographs in the plotter, relative orientation, absolute orientation, contouring and the recording of planimetric details. From the point-of-view of setting the photographs in the plotter the principle of the analytical plotter offers definite advantages, since the inclination of the photographs is not necessary. Uncut film strips may be used, if the shifts necessary for measurements are introduced to the measuring marks instead of shifting the photographs as was mentioned in the explanation of the principle of an analytical plotter.

The time normally spent for relative and absolute orientations can be almost entirely saved by using the values of orientation elements and the coordinates of air stations, as obtained from the adjustment of analytical triangulation. These data may be recorded, for example, on punched cards which in turn regulate the settings of constants in the computer of the analytical plotter. The use of minor control-points in the actual plotting is therefore unnecessary. This is of great importance from the point-of-view of automation, because the problem of the identification of minor control-points is entirely solved when this possibility is utilized. For contouring, the Automatic Scanning Correlator (2) may be employed and the planimetric details may be recorded, using an electronic scanning and printing technique (3) to obtain a result similar to that provided by the "orthophotoscope," (4) if so desired.

In large-scale mapping the coordination of triangulation and plotting is not of the same importance. Instead, the highest accuracy is often required, particularly in the cases of certain important points such as boundary monuments, etc. Here automation is of lesser importance, but sundry other advantages of the analytical plotter may be illustrated. Several points pertaining to the accuracy have been already mentioned. For example, numerical methods of relative orientation may be advantageously used; even analytical relative and absolute orientations according to the method of least-squares are technically possible, although perhaps economically unsound at the present moment. In addition, any correction that can be determined, can be also taken into account. This applies also to corrections that are known as a result of experiments and may not be theoretically explained.

It is apparent that this property of the analytical plotter may be a great advantage. *Over a suitable test area the entire system of photogrammetric mapping may be calibrated as a whole, and the necessary corrections introduced when plotting.* This has not been possible before due to the difficulties encountered in introducing arbitrary corrections in a practical way.

Summary

The above presents the analytical plotter in general terms. Its principle and advantages are briefly described, and relevant subjects briefly reviewed to clarify the place of the analytical plotter in the photogrammetric production line. This production line may be the conventional one, or may be an integrated system of analytical methods. In the first case the analytical plotter is an improvement that brings about numerous advantages. In the second case the analytical plotter is a key link in a chain of photogrammetric operations that lends itself particularly well to the application of electronic and data processing methods; methods which will undoubtedly dominate the future of photogrammetric mapping. In both cases the analytical plotter is expected to improve considerably the performance of photogrammetry.

Improvements are obtained in many fields: Means are provided to increase the accuracy of photogrammetric plotting, to produce instruments of wider versatility and of greater speed of operation, etc. Additional economic advantages are brought closer by making possible the application of automation to certain photogrammetric operations. In view of all these features the place of the analytical plotter in the photogrammetric production line appears to be well secured.

References

1. Helava, U. V., "New Principle for Photogrammetric Plotters; and Moore, W. J. M., "Consideration in the Design of an Electronic Computer for a Photogrammetric Plotting Instrument," *Photogrammetria*, 2, 1958.
2. Automation in Stereoperception, Photographic Survey Corporation, Toronto, 1958 (Special publication).
3. Ross, Capt. Leroy E. and Levine, Dr. Samuel W., Universal Electronic Rectifier, Photogrammetric Engineering, Vol. 24, No. 5, page 789, 1958.
4. Bean, Russell K., "Use of Orthophotoscope," Photogrammetric Engineering, 1, 170–180, 1957.