# STANDARDIZATION OF ANALYTICAL PLOTTER INPUT, OUTPUT, AND ALGORITHMS

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The conversion (in mapping) from traditional analog instrumentation to the analytical stereoplotter is a major step which requires a whole new look at the mapping process as it is presently performed. In the past, new forms of instrumentation were introduced and in most cases could be integrated into the process because they did not represent a radical change in procedure or the resulting process could be separated from standard products (e.g. orthophoto production). Fortunately, the introduction of analytical processes were simplified because they were restricted to aerotriangulation which in most mapping facilities is separated from compilation. The analytical stereoplotter, on the other hand, represents a new concept in instrumentation coupled with complete numerical (analytical) procedures. That is, it represents an instrumental concept that is applicable to both aerotriangulation (control densification) and compilation (data extraction). To take full advantage of the concept one should review the present standard procedures and modify them where necessary to maintain continuity and standardization.

Let us first look at what might be considered typical general steps (or processes) presently used in the production of maps. Major steps in the process are: planning; field acquisition of data; triangulation; compilation; and reproduction. Although all these steps could be made more efficient by applying modern digital techniques, the two that are most affected by the introduction of the analytical stereoplotter are the next to last two, namely triangulation and compilation. Through the years these two steps have evolved into two distinctly separate operations even though the utilize similar basic photogrammetric techniques. This evolution was spurred on by the development of highly precise mensuration instruments for triangulation whereas the compilation instruments were designed more toward ease of operation and versatility. In the past, the two separate operations could be tolerated because of the nature of the problem being solved. That is, in order to extract data from a pair of overlapping photographs, the photogrammetrist must introduce seven known conditions of model space (i.e., establish a state of equilibrium for the model). These seven conditions are 3 rotations, 3 translations, and a scale. If absolute values are not given, he assumes certain conditions about one of the photographs, adjusts the adjoining photograph and creates the so-called "relative orientation." If, in addition, he has known coordinates (7 values) of strategically placed points in the model area and makes the necessary adjustments of the photographs to fit these points, he has established the so-called "absolute orientation." To extract meaningful data, the operator must have an absolute orientation of the model. Therefore, it has been common practice to provide a "plot sheet" which has at least two points in a scaled horizontal position (X and Y) and three defining the vertical orientation (Z). The coordinate values for these plotted points are determined from given "geodetic" positions using

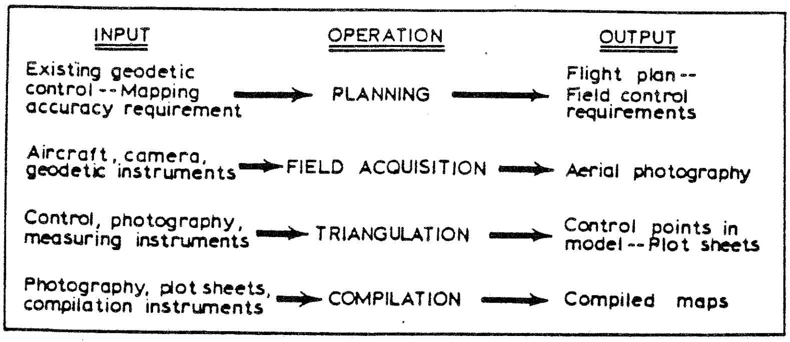


Figure 1

aerotriangulation techniques and the compilation sheets are plotted either by hand or by machine. A typical operation is shown graphically in fig. 1. Since each of the operations shown in the figure employ separate and unique instrumentation and procedures, it is a logical flow even though it involves a certain amount of duplicated effort. The major duplication is the repeated orientation of the stereomodel. In addition, using these methods there is (of necessity) a great deal of repeated manual introduction of data leading to possible blunders.

In contrast to the analog methods, the analytical stereoplotter offers a completely numerical approach to the process whereby repetitive steps can be eliminated and the data handling can be structured toward a completely digital system. This concept is illustrated in figure 2.

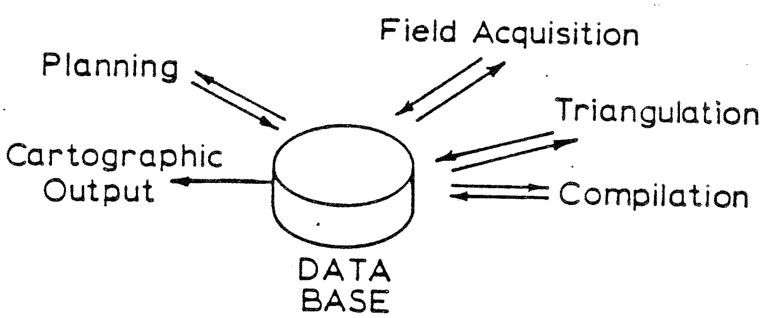


Figure 2

In the figure, a data base (consisting of various stages of parameter estimation) contains all the information that is required for using digital methods in the various operations. For instance, existing geodetic control for an area along with a fictitious data generator and adjustment programs can be used in "planning" to compute optimum airstation positions and additional field control requirements, along with predictions of the statistical estimates of the aerotriangulation results. These data can, in turn, be used in the aircraft for navigation and exposure control, whereby the actual measured coordinates of the airstation during the acquisition can be returned to the data base for use as approximations in the adjustments of the aerotriangulation data. Using standard analytical methods, the triangulation process computes precise airstation data for the photography and thereafter, this data is used directly in the compilation instrument for data extraction, negating the repeated orientation process and the necessity for any type of pre-plotted worksheet. The data base, therefore, becomes the controlling factor for the entire process and, as such, must be well designed and general. More importantly, the definitions of the data in storage must be consistent, unambiguous, and require a minimum of post- or pre-processing. Likewise, the algorithms used in the various stages of data manipulation must be concise, rigorous, and consistent.

A good example of the need for consistency was revealed in a recent inquiry memorandum mailed to members of Commission II, WG II/1, by S. Wu. In the memo, Dr. Wu requested information on "parameters necessary for the evaluation of an analytical plotter." His request was prompted by a discussion in Ottawa whereby the Subworking Group on Software Development decided that they should focus their attention on "trying to define those parameters to be used to evaluate an analytical plotter." Parameters, in this case was meant to be the numerical descriptors associated with a pair of photographs. The accompanying questionnaire requested opinions on three basic sets of parameters--those associated with the camera, the photography, and the model. Of special interest was the list of items associated with "model parameters and ground control." On reading it, one comes to the conclusion that there exists as many "methods" of forming a stereomodel as there are analytical systems on the market. Obviously, with the present variations in hardware and operating systems, one cannot expect to establish a universal software. However, it is reasonable to suggest that a standard be established for the definition of parameters and, in some cases, the algorithms for computations. If this were done, data could be easily exchanged and tests of equipment could thereby be standardized. Early in the study at the National Ocean Service, NOAA, it was recognized that any organization must standardize in order to realize the full potential of an analytical system.

To amplify, let us look at a graphic description of an analytical stereoplotter in figure 3.

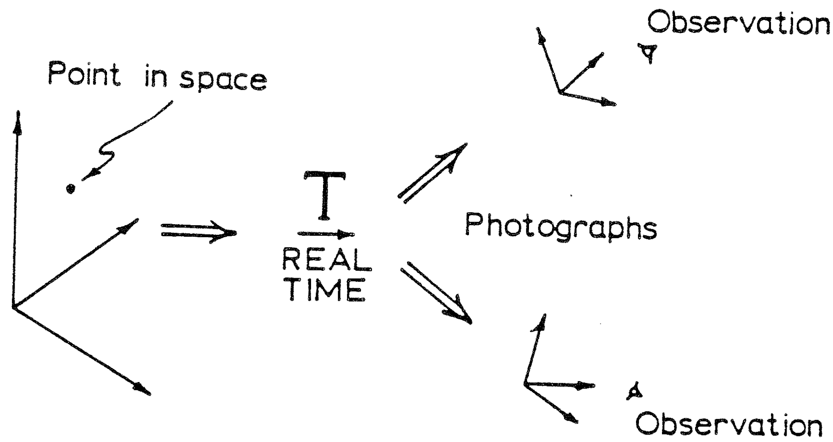


Figure 3

Simply put, the process involves some mathematically defined point in space that undergoes a transformation in order to position each photograph relative to an optical system viewed by the operator. If the system is correctly defined, the operator will view a stereoimage of the special object. The operator has control over the point in space and can move it around for the purpose of extracting data (so-called compilation). Orientation (a sub-set of triangulation), on the other hand, is an inverse of this process. Here, the operator adjusts the photographs to point at common images whereby the resulting "measurements" are used to compute a correct "definition" of the photographic system. The system, therefore, is completely reversible. In fact, the process of "measurement" for triangulation can be done on any comparator (not necessarily in stereo) and the resulting "definition" should be directly applicable to any other analytical compiler if there is consistency between the two systems. The main point here is that in the process of triangulation (the solution of the measurements), the orientation of each photograph has been computed and should not have to be repeated in the compilation process. In fact, if the triangulation was computed for a block of photographs, the solution of the block system is more homogeneous than any repeated orientation of only two of the photographs from the block. Data from the block adjustment holds for <u>any</u> pair of photographs from which an operator may want to extract data. For instance, if the block were made up of photography that have two-thirds forward overlap then alternate photographs could be used for data extraction with no loss in accuracy of the orientation process! In fact, the compilation process should be more accurate since the operator is now working with photography with a greater base-height ratio. To repeat, the procedure is feasible <u>only</u> if all the processes are consistent.

Where in the process should one first concentrate on standardization? An expansion on that part of the proceding figure 3 that depicts object space might help to answer this question. Figure 4 brings out the fact that most applications of photogrammetry are concerned with mapping the earth's surface which is a curved figure. Geodesists have chosen to describe the positions of points on the earth's surface with curvilinear coordinates and Cartographers have chosen to present flat maps of the earth with a host of mapping transforms.

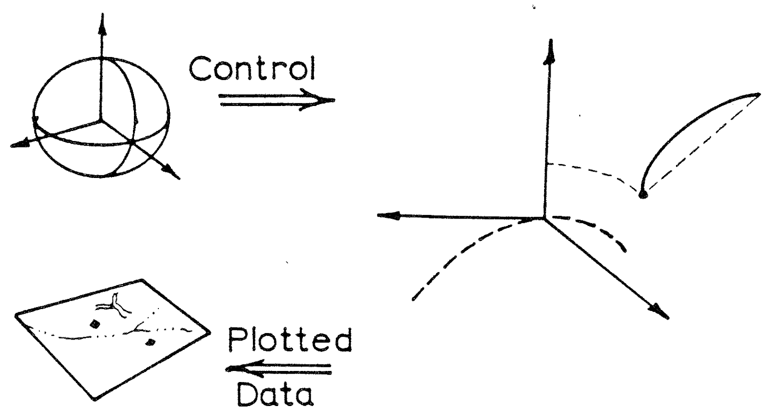


Figure 4

The rectangular coordinate system shown on the right in figure 4 is the one chosen by the photogrammetrist which best suits the pair of photographs being employed and also minimizes computation of the central perspective transformation to each photograph. This system is usually unique for each photopair and as such does not qualify for standardization. Likewise, the output coordinate system for plotted data is usually chosen in particular for the "best fit" to the area being mapped and as such can take on a variety of shapes. The most universal of the three (upper left in fig. 4) is that of the geodesist--the curvilinear system in latitude, longitude and height. These systems are usually consistent over large continental land masses and are precisely defined by two parameters--either two axes of an ellipsoid (a and b) or by one axis (a) and an eccentricity (e-squared). Sometimes the figure is given by the axis (a) and a flattening (f), however there are expressions that relate the four parameters. Most important is the fact that there are rigorous transformation to and from Cartesian coordinates. That is, to transform from geodetic coordinates ($\phi$, $\lambda$, and h) to Cartesian coordinates (X, Y, and Z), one uses (assuming positive longitude west):

$$\left.\begin{aligned} N &= a / (1 - e^2 \sin^2 \phi)^{1/2} \\ X &= (N + h) \cos\phi \cos\lambda \\ Y &= -(N + h) \cos\phi \sin\lambda \\ Z &= \{N(1 - e^2) + h\} \sin\phi \end{aligned}\right\} \quad \cdots\cdots [1]$$

Conversely, to transform from Cartesian to geodetic coordinates:

$$\left.\begin{aligned} k &= (X^2 + Y^2)^{1/2} \\ \lambda &= \cos^{-1}(X/k) \\ \phi &= \tan^{-1}\{Z(a+h)^2 / k(b+h)^2\} \end{aligned}\right\} \quad \cdots\cdots [2]$$

Fortunately, the earth's curvature can be introduced in the analytical stereoplotter in such a way that the solution for latitude can be approximated by a direct solution as shown instead of the traditional iteration. This is done by selecting the origin of the plotter rectangular coordinates as the sea-level-midpoint of the line joining the nadir points of each photograph (figure 5). An adjustment in the Z coordinate for the transformation to each photograph can be approximated (with negligible error) by:

$$\Delta Z = (X^2 + Y^2)/2a \quad \ldots\ldots\ldots [3]$$

The un-adjusted Z is identically h as used in the direct inverse transformation above. Having the coordinate system at the "model" center also simplifies the computation of atmospheric refraction. To bring the coordinates of equations [1] into the local system one computes a translation $\Delta X$, $\Delta Y$, and $\Delta Z$ using [1] and the average air-station latitude and longitude along with an h of zero. Additionally the system is rotated so that the model X-axis passes through the airstation nadirs and the Z axis is "vertical."

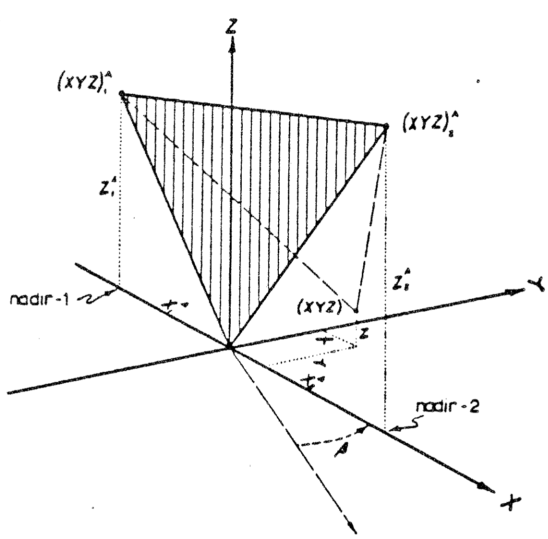


Figure 5

Once computed for the model (as an initial step) the inverses of these transformations can be used to output geodetic coordinates. For compilation plotting, the operator can select any of the myriad of mapping transforms he may wish. Another valid point for consideration is that the majority of national cartographic data bases are made up of coordinates in a geodetic system--therefore, it seems logical that the photogrammetrist should follow and output geodetic coordinates.

To complete the picture for standardization of object space, one must consider the three remaining parameters that describe the spatial orientation of a photograph. These are the three angles which define the rotational attitude of the camera in space. For consistency these parameters should describe the angular position of the camera relative to the local vertical of the geodetic coordinates of the airstation position. If this is done, simple transformations can be computed to bring these angles into the rectangular system selected for the "model." In this way, any photograph can be immediately orientated with any other without the need for any intermediate parallax measurement and computation. In fact, it is possible that adjoining photographs from different projects (and times) could be directly "set-up" (a valuable tool for change detection, etc.). The only measurement that is necessary is the requirement that the operator "define" the relationship between the photographic and machine coordinate systems (interior orientation). This requires that precise pointings be made of the camera's imaged fiducial markers.

The third area of concern for standardization is that one which describes the internal characteristics of the camera. Fortunately, this falls in the purview of Commission I of ISP&RS and is presently being addressed by H. Ziemann of the National Research Council of Canada. Hopefully, Dr. Ziemann will be successful in establishing a universal system of describing the distortion of a photographic lens that can be easily adapted by the users of analytical stereoplotters.

In this suggested "standardization," all of the internal computations for servo response are left to the ingenuity of the designer of the analytical stereoplotter. On the whole, the form for these computations are usually dictated by machine design and computer speed. The accuracy, ease of operation, flexibility, speed, etc. are all characteristics of individual design which can be measured if the input and output are standardized. More important, if one is given two photographs with six consistent parameters each (along with camera characteristics), he can place them in his plotter--make precise points on fiducials and proceed to directly extract data.