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The Role of Software

The philosophy of software is professionalism!

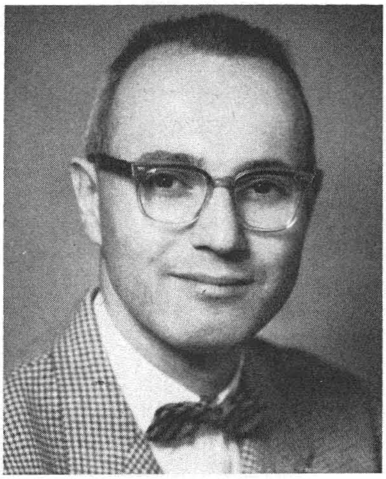
(Abstract on the next page)

PHOTOGRAMMETRIC DATA ACQUISITION is the process of transforming phenomena from an object space occurrence to an image space record. In most instances, the object-space phenomena is a four-dimensional entity—three dimensions of position and one of time. The image-space record is in most cases of three dimensions—two dimensions of position and one of time. If the transformation is by a central projection, and one considers the principal distance of the storage record, then there are also four dimensions of image space. Photogrammetric data reduction is the inverse transformation from the image-space storage record into usable object-space information. (Rosenfield, 1961). This inverse transformation may be performed analytically, analogically, or by appropriate combination of the two.

Photogrammetric systems thus encompass both the data-acquisition and the data-reduction phases of the operation. The purpose of a system would be to establish useable data by indirect measurement of the object-space phenomena. For various reasons the occasion under study may not be accessible or amenable to direct measurement (for example, the sloshing of fuel inside the tanks of the Saturn rocket during liftoff). Thus, the concept of remote-sensing systems is only an extension of normal photogrammetric thought.

THE DATA-ACQUISITION PROCESS is performed through the use of special instruments which normally operate within bands of the electromagnetic spectrum. The usual photogrammetric instrument is a camera operating in the visual spectrum, based on the principles of the idealized central projection. The optical lens is the usual receptor, and the photographic emulsion is the usual sensor and storage medium. However, other instruments are already in use which operate in other frequency bands. The PPI or side-looking radar instruments operate in the radio-frequency spectrum, and are based on the principles of a range-and-time projection. These are active systems using transceiver antennas as the receptor, cathode ray tubes as the recorder, and usually employing a photographic emulsion as the storage medium.

Infrared instruments operate in the IR spectrum and are based on the principles of an angle-and-time projection. An optical train is the receptor, heat-sensitive, super-cooled crystals are the detectors, cathode ray or glow tubes are the recorders, and the photographic emulsion is the usual storage medium. Laser and holographic instruments are already in use. Accoustical instruments (already used in under water sonar) may soon be with us, and who knows what the future may bring. Whatever the technique, an instrument is the basis of the data acquisition systems. This is the realm of hardware.



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ABSTRACT: *A photogrammetric system includes both the acquisition and the reduction of data. A mathematical model accompanies a system for transforming input data into output information. The investigation of the causes of systematic errors, their expression as mathematical models, the techniques for calibration, and thus the elimination of the effects of these errors, are important applications of software available to the photogrammetrist. Two different philosophies of data reduction include the pure mathematical-statical approach, and the technological approach. The geometric quality of an image-object ray is a function of the characteristic values of the covariance matrix of the transformation parameters.*

THE DATA-REDUCTION PROCESS provides useable data in either a graphical or a digital presentation. The graphical presentation may be a map or chart, a map substitute (such as a mosaic or orthophoto), a line drawing (such as an architectural presentation), etc. The digital presentation may be a hard copy tabulation, a magnetic tape, disc or drum storage, a deck of cards, etc. Instruments may be used entirely or partially for the data-reduction process. The term *photogrammetry* encompasses the meaning of *measurement*, and a measuring instrument of some type is part of the data-reduction system. The most common measuring instrument is the comparator, either monocular or stereoscopic. It may be used as a separate operational instrument or as an integral component of a larger, more complex instrument.

The solution of the inverse transformation is a mathematical process which may be performed by an analogical computer such as one of the usual mapping instruments with which we are all familiar. The solution may also be performed by an analytical computer, one of the high-speed electronic digital computers, with which not so many of us may be familiar. Finally, the solution may be performed by one of the combination analog-analytical computers which are newly with us—the O.M.I. Analytical plotter, or the Bunker-Ramo UNAMACE*. The data reduction process is the realm of both hardware and software.

Both the data-acquisition instruments and the data-reduction instruments are designed, manufactured, and adjusted to perform their required functions within a particular level of geometrical quality, and to meet specified output quantity requirements. The design and engineering of instrumentation is a hardware problem.

The data-acquisition systems are based on the principles of projective geometry and thus may not record within a single instrument all of the data necessary to perform the inverse transformation. Even when sufficient data are so recorded, the transformation is bound by geometry, and may be weak in its ability to reconstruct the model with the required geometrical quality. Thus advanced planning is needed prior to any acquisition experiment to assure that adequate instrument coverage is available to meet the transformation requirements of quality and quantity. This is the realm of software.

THE RECORDING AND STORAGE of transient phenomena by acquisition instrumentation is not an idealized procedure. We live in a real world which is a realm of perturbation. Environmental phenomena perturb the direction of rays in both object and image spaces. Mechanical components and the dynamical characteristics of the instrumentation system perturb adherence to the principles of the ideal geometric projection. These perturbations are the sources of errors in the photogrammetric systems. Optimum design, engineering, and manufacture of acquisition instrumentation reduce these internal errors to the level of acceptability. Optimum design and operation of the data-acquisition experiment reduce environmental errors to an acceptable level and furnish adequate geometric strength to the transformation solution. The same optimum requirements of designing, engineering, manufacturing, and operating are applicable to the data-reduction instruments.

If the instrument by itself cannot meet the

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* See "UNAMACE Tests" by Edward F. Burzyncki in PHOTOGRAMMETRIC ENGINEERING for March 1967, pp. 273–277.

geometrical quality requirements, it may still be possible by proper calibration to achieve additional accuracy. The calibration procedure consists of determining an appropriate error model to describe the systematic errors of the instrument. The correction is then performed by operating on the observations from the instrument with the correction equations obtained from the computed error model. As calibration may not be an entirely stable condition, it may be necessary that recalibration be performed at periodic intervals. (Rosenfield, 1962).

THE DESIGN OF THE photogrammetric instrumentation is the role of the optical instrument designer, the optical and mechanical engineer, and even the electronic engineer. The instrument must perform to meet its design requirements. It must be stable, adjustable and able to maintain its adjustment, amenable to calibration and able to hold its calibration.

The design of the data-acquisition experiment is the role of the photogrammetric instrumentation engineer. The distribution of the instrumentation complex must achieve adequate geometric strength in the solution parameters. The number of instruments in the net must be adequate to achieve redundancy, assure randomness, and allow favorable error propagation. The experiment design must accommodate the data-reduction procedures which are available or are to be developed. The engineer must know the geometrical quality of the observations obtained from his instrument system.

The design of the data-reduction system is the role of the photogrammetrist. He is the systems-measurement technologist. From the software point of view, the data reduction is to be performed by analytical techniques using the electronic digital computer. The photogrammetrist is the technologist who prepares the mathematical models representing the transformation system. These models, which are in the form of mathematical equations, are turned over to the programmer who prepares them for electronic computation and solution. The data-reduction analyst obtains the observation measurements from the photogrammetric technician and prepares them for entry into the computer program.

The experimental data and constants, together with the computer program, are turned over to the computer operator for running on the computer. The resulting computer output is returned to the data-reduction analyst for preparation in final form to meet the user requirements. The technologist will validate the results and assure that all requirements have been met. He is ultimately responsible for the entire data-reduction cycle from mathematical analysis of the entire data acquisition and data-reduction system to validation of the test results.

A MATHEMATICAL MODEL must be prepared which expresses the projection upon which the acquisition instrument is designed. This model for the projection relates the image- and object-space data. A computing algorithm must be developed to solve the geometrical problem that transforms the image-space data to object-space information. An error model must be developed which expresses the relationship of all known systematic errors of both image space and object space causing perturbations from the ideal mathematical projection. The investigation of the causes of systematic errors, their expression as mathematical models, the techniques for calibration, and thus the elimination of the effects of systematic errors, are some of the most important software applications available to the photogrammetrist.

There is an important topic which concerns different philosophies of data reduction: the pure mathematical-statistical approach *vs.* the technological approach. The mathematical-statistical approach is based solely on the error model. It considers that all instrumentation problems can be solved in the data reduction process, if only a good enough mathematical error model can be formulated. The technological approach is based on a more involved philosophy: first, that the instrument system is designed, manufactured, and adjusted to the highest degree possible; and second, that each contributing error of the system is isolated, analyzed, and corrected before the major data-reduction adjustment takes place. Personally, I am a proponent of the technological approach to instrumentation data-reduction systems. (Rosenfield, 1963).

In support of my position, I should like to quote from Hald, 1955.

> "The formulation of a mathematical-statistical model which gives a satisfactory description of the data, is not in principle a statistical task, but belongs within the professional subject from which the observations have been derived. In practical work, however, we often find that professional knowledge is so small that it is not possible to formulate a proper (theoretical) model, i.e., a description based on general laws regarding the process which has generated the observations. In such cases the specification becomes

> merely a phenomenological description, i.e., a purely empirical description of the observed phenomenon without any attempt at linking up this description with theoretical reasoning based on professional knowledge.
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> " . . . It should, however, be born in mind that in the long run it does not pay to be satisfied with a phenomenological description; this should be resorted to only when all attempts at giving a theoretical description have proven impractical."

THERE IS ANOTHER ASPECT of the error model which requires discussion. That is whether to include the error model as part of the fundamental projective equations, or to correct for that systematic error prior to entry into the projective transformation. The answer lies in a two-fold consideration. The first consideration is in the slopes of the error surfaces. If the error surface presents a complex model, with steep slopes, and possibly with many discontinuities, it may not be possible to develop an exact mathematical expression in closed form. The problem may be due to poor workmanship in any of the component phases of the instrumentation system. An error model for such a case would be an approximation at best. It might be a better solution to reduce the error at its source—to determine the underlying cause (poor design, engineering, manufacture, geometry, etc.) and to make the necessary corrections in the instrument or in the experiment design. The errors that do lend themselves to error model expression, or to calibration, are those with small magnitudes, shallow slopes, and continuous surfaces.

The second consideration is in the covariance matrix of the computed parameters. The geometrical quality of a directed ray is a function of the characteristic values of the covariance matrix of the transformation parameters. The matrix whose rank expresses the minimum number of parameters necessary for the projective transformation, and which was determined by adequate over-determination, represents the minimum dilution of the geometrical quality of the directed ray. Increasing the number of parameters above the minimum required, by incorporating the error model as an integral part of the projective transformation, increases the magnitude of the characteristic values of the covariance matrix and thus introduces unnecessary dilution on the geometrical quality of the directed ray. (Eichhorn, 1965).

THE PHOTOGRAMMETRIC ANALYST is not a magician: conversely, there is nothing magic about the analytical process. He cannot solve problems for which he is not given the necessary fundamental information—he cannot turn bad data into good information. In order to provide the ultimate user with information meeting his requirements, it is advisable to consider some thoughts on the concept of experimental design in photogrammetric data operations. Such an occurrence is a complex experiment of an expensive and important nature. As such it is imperative that as much information as possible be derived from each operation.

In order to obtain the desired data to as high a geometrical quality as possible, it is necessary that consideration be given to the rigorous and complete design of the entire test experiment. This includes the thoughtful considerations of experts in the allied fields of planning, engineering, instrumentation, data processing and data reduction, and sometimes even in instrument design. It is only by effecting coordination through the medium of meetings and conferences, sufficiently in advance of the data operation, utilizing the experience and abilities of the specialists in the above mentioned fields, that the user (who is usually paying for the entire process) can be assured of obtaining his required data to the desired degree of accuracy. (Rosenfield. 1960).

There is no substitute for adequate instrumentation and proper data-acquisition and data-reduction planning. All phases of the data experiment must be thought out and considered in advance. Comprehensive calibration of the instrumentation system must be performed. Necessary measurement of static and dynamic components of the system must be made. The system must be stable enough to hold its calibration and dimensional characteristics throughout the duration of the data experiment. Sometimes, certain characteristics do not hold true. Secondary component standards are then necessary to allow dynamic calibration and error correction. The use of the reseau to correct for dimensional instability and non-flatness of the base is an example of this type auxiliary. The use of additional information is another solution to the poor instrumentation problem. This could be data in the form of additional ground control to allow solution for the coefficients of an error model which approximates the source of the systematic errors to be eliminated. This is the least desirable of the possible techniques. In the first place, additional ground control can be expensive or not possible to obtain. That which is acquired may in itself be susceptible to large error. And finally, an error model has to be developed to represent systematic errors which may not conform to the error model requirements stated earlier. In short, good analytics is not a substitute for good instrumentation.

ANOTHER MAJOR APPLICATION of the role of software, and specifically for the role of the comprehensive error model, is the error model which is incorporated into the projective transformation. This is in the area of simulation of the data experiment. The all-inclusive error model in a simulation experiment is not used to establish the direction of a ray in space. Instead, it is used to represent the actions and interactions of the systematic errors on the projective transformation.

The *covariance matrix* of such a system indicates the relative contributions of the various errors to the system. When realistic weights (proportional inverse of variances and covariances) have been assigned to the error and transformation parameters, the covariance matrix represents the actual error contribution to the directed ray. The serious error sources can be singled out for further study and hopeful elimination. Correlations can be determined for their deleterious effects. Optimum geometry can be selected and an adequate number of instruments for the net can be determined. Ultimately a sophisticated data experiment can be performed, based on knowledge acquired during the simulation procedure.

A mature instrumentation system is represented by a completely documented software package which expresses the entire data reduction system, with all its error calibrations, projective transformations, and computing algorithms in such a manner that ultimate reduced data and valid error propagations can be obtained. All analyses must be theoretically correct and not include any expedient approximations. In this manner, future minor improvements in knowledge or hardware will not necessarily require major modifications to the analysis and computer programs. All algorithmic computations and error propagations must be statistically valid so that the resulting data are not susceptible to criticism.

The ultimate goal of software analysis is to bring the instrumentation system under statistical control. All systematic errors are known and eliminated by proper instrument design, adjustment, or calibration. All component random errors are validly estimated. An error budget representing the component error contributions to the reduced data is formulated. And finally, the reduced data, when compared to an outside standard in an operational test, compares favorably with the propagated error, and the error budget.

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