*Fiftieth Anniversary Highlights**

Photogrammetry—1984

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PHOTOGRAMMETRY—The science and art of extracting useful information from photographs by measurement and interpretation of images—has evolved during the past century to become a useful, even widely accepted, tool of today's science and technology. A number of functional instrument types are available covering a broad spectrum of accuracy characteristics and offering a range of production capacities which are roughly proportional to the tolerable errors. Within this availability of instrument types, the potential user can usually determine in a short time whether or not his particular problem can be economically solved by photogrammetric operations —in a disconcerting number of cases, he determines that it cannot.

The material universe exists, with respect to man's senses, as a continuum which can be interrogated sensually to furnish information for reasoned actions by man. From this is the whole of man's apparent rationality derived—indeed, this is the set of conditions which defines man as "sapiens," that he manipulates information before he moves matter, to a far greater extent than do any other known forms of life.

Early in his existence, man learned that a very small amount of ordered matter can contain a very large amount of information, and that manipulation of some small masses can be used to communicate information to many men about larger masses. With this discovery of alphabet and number as data symbols, civilization became possible. However, it is imperative that we remember that the symbol but evokes the sensual concept held in memory—it does not and cannot define or duplicate the quantity of information represented directly in even a microscopic mass. For this reason, attempts to reduce any portion of the material continuum to pure symbolic form are doomed to failure. This does not mean that symbolic transfer of information is less than the civilizing catalyst it has proven to be; it does mean that reduction of the material world to symbolic form must be highly selective, if the task is not to overwhelm both scribe and reader. Useful information must be sensed, and may be manipulated into still more usable form, with or without conscious symbolization; and selective filtering may occur at any point in the information system from sensing to final utilization.

Within this philosophical framework, the field of photogrammetry can be defined as the manipulation of information in the form of light energy (a continuum of essentially zero mass) which has been modulated in amplitude, frequency, or both, by passing through and reflecting from mass. This varying energy pattern does not embody all possible useful information contained in the masses which modified it, but it does contain a much larger proportion of this information than does any conceivable symbolization intended to represent these masses. Thus, the photographic sensing offers for man's manipulation a package of information about the material world which is more comprehensive (hence, potentially more useful) than any symbolic structure. The photographic sensing may be directly manipulated, or it can be made to react with matter ("exposure") to arrest the light-energy continuum at chosen points in time (with some considerable loss of information content, but still containing more information than can be consciously symbolized).

Because photographic sensings contain such a relatively high proportion of the available information about masses, we should logically expect photogrammetry to be the principal information-processing system in use by man to obtain and manipulate data about the material world. Wherever man performs actions based upon information about real objects—whether in shaping masses with tools, directing the flow of traffic in transporting masses, evolving theories about micromasses from cloud-chamber experiments, and about macromasses from astronomic sensings—even in mapping the earth!—photogrammetry as an optimum information system should play a part; in many if not in most cases, the principal part. That photogrammetry is not today so applied to the extent of its theoretically high potential is obvious.

It is pertinent to discuss the possible reasons for the present restricted use of photo-

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grammetric techniques, and if possible to develop a logical framework for planning its wider acceptance and utility.

Photogrammetry involves both *measurement* and *interpretation* functions, and because present systems require that the human operator perform both of these functions (in addition to systematic *interrogation* of the data and *recording* of the manipulated information), we have reached a point where the amount of photographic sensings available vastly exceeds our capacity to manipulate and interpret the data they contain. Since the supply of manpower gifted with the required aptitudes is limited, while our potential ability to sense photographically is virtually unlimited, our attempts to solve this dilemma by recruiting and training more and more photogrammetric instrument operators and photointerpreters will not do more than emphasize the criticality of the problem. Its solution must lie in the discovery of means to increase the productivity of the photogrammetric process, without reducing the validity of the information extracted from photography.

Automation may offer this increased productivity—IF we first can derive and support conclusions categorizing those functions which are best performed by machine methods, and those which require human judgment beyond the economic or theoretical capacity of machines to perform.

Empirical data and considerable theoretical work in operations research and the information sciences tend to demonstrate that human beings are very much superior to present-day machines in deriving analogies and synthesizing conclusions (the interpretation function), while machines can be utilized to greatest advantage in performing programmed comparison functions (measurement, for example, is a form of comparison; as are many transformation and translation operations). It follows that any operation which can be reduced to direct comparison routines, however complex, can probably be automated to advantage; while those operations which cannot be reduced to some conscious form of comparison are, at the present time at least, not likely subjects for automation.

An optimum system designed on these concepts would probably be approached:

First—By defining the operations which must be performed.

Second—By determining the logical sequence of these operations.

Third—By ascertaining the man-machine relationships which this sequence defines, and

Fourth—By specifying the operational characteristics of the required men and machines and their points of contact.

When such an ordering process is completed, we should then be ready to design and implement the machine structures and operator training programs to activate the system, with reasonable assurance not only that it will work, but that it will work better than any alternative system which can be advanced today.

Applying this approach to photogrammetry, we must group at the beginning of the photogrammetric information processing system all of those operations which are likely candidates for automation; for, if the task of designing and building the automatic machines to perform this group of operations is competently done, we shall thereby release the human operator entirely from the exacting and time-consuming tasks of interrogation and measurement, and may expect significant increases in overall productivity from his release. This follows because:

First—those tasks which machines do well, they do very well indeed by comparison with human speeds and human accuracies, and

Second—the human operator, functioning now in his superior capacity as interpreter and filter, can select material from a vastly augmented store of pre-interrogated and pre-measured and recorded data.

In any photogrammetric data system, the functions of interrogation and measurement ("systematic looking" and "comparison with standards") on the photographic images are fundamentally translation and comparison operations; while the identification of patterns and determination of their meanings and relative usefulness as information are primarily human interpretation functions, far beyond the economically feasible capacity of man-made machines. (Analogously, if I wish to know the number of vehicles passing a given milestone, a machine can be devised to systematically count the number of things heavier than *M* or larger than *A* which pass—and my machine will do this without appreciable error or fatigue. If, however, I wish to categorize these vehicles as "commercial or private," "make and model," "male or female driver," I can no longer economically design and build a machine which will approach the average high-school boy in performing this categorization.)

It may be impracticable to realize the ideal grouping of all functions in all real photogrammetric data systems, since in some applications, identification and interpretation of a few images are required human functions at or near the beginning of the process (for example, in the case of topographic photogrammetry, control identification is a requirement). However, even where this situation exists, the difference between human interpretation of four, or even twenty images and human interrogation of thousands is significant; and any system which reduces initial human operations by this amount would be a major improvement over its predecessors.

In almost all its applications, the photogrammetric process is used to manipulate and deliver data concerning three-dimensional objects; and since (with rare exceptions indeed) the photogrammetric sensings are sampled in two-dimensional perspective projections, the overwhelming proportion of photogrammetric information handling involves stereoscopic pairs, or perspective point view-pairs, of photographic sensings. The optimum system, then, should be able to accept as input these perspective pairs and to perform the required manipulations to deliver transformed and filtered data in usable format and language—often in more than one format or language for different uses. Further, because we are dealing with sensings of real objects having real relative positions, configurations, and dimensions, we must in some way relate the two views and the images they contain to each other and to the field in which the objects are sensed (relative and absolute orientations). We must then systematically interrogate the images in the area common to both sensings, adapt the information thereby obtained to a consistent reference system, and record selected portions of the reduced data in the desired format and language on or in the proper media. In any real system, we will impose realistic limits on each of these operations, with the intention of expanding these limits wherever economic justification exists. Important to this analysis, however, is the understanding that, regardless of the limitations of sensors, emulsions, reference systems, language forms, or output media; the fundamental operations of orientation, interrogation, manipulation, recording, filtering, and interpretation must be performed before the stereophotogrammetric information system can yield data for human decisions.

Taking these in order, orientation operations take two forms; relative and absolute. In the first form, only image correlation is required, which indicates susceptibility to automation. Absolute orientation, however, requires both identification and interpretation of images as well as image correlation—thus requires human intervention (although, since some correlation is involved, machine assistance should be advantageous in this operation).

Interrogation, the next step in the logical sequence, is defined as the systematic observation of the area covered by the stereopair of sensings, and may involve some human interpretation and selection in special cases; but in the general instance, interrogation must include image correlation and hence is properly a subject for automation.

Manipulation of the information to adapt it to a common reference system requires only the translation of a set of measurements to conform to an assumed set of criteria—a correlation operation which is again suitable for automation.

Recording the data presently involves selection (a human function at the decision level, but one which for many cases can be decided once and criteria defined, then set up as a constant correlation factor, hence, automatable), translation to the required language and format, and the impression of this format and language in or on the chosen media for use and storage (in this sense, a machine tool impresses form on matter and thus records). Since it should be feasible, and certainly would be advantageous, to postpone selection until after the recording stage in many photogrammetric systems, the entire recording operation may well be automated—in fact, the translation and form-impressing functions of recording are being done automatically in more than one present-day photogrammetric information system.

Filtering can be defined as the rejection of data interpreted as unimportant, in which definition "interpretation" retains its classic meaning of identifying ("attaching human meanings to") data, on the basis of which identification human decisions may be made. Both filtering and interpretations required for filtering almost certainly demand the exercise of human judgment, and if they are performed elsewhere than at the output end of the decision system, all subsequent operations in the photogrammetric system must await the completion of the relatively slow interpretation process. If, however, interpretation is to be performed only at the output end, the whole of the data contained in the original photographic sensing must be available to the interpreter and must therefore be processed and manipulated through the entire system, with an absolute minimum of accidental or deliberate filtering during sensing, interrogation, manipulation, and recording. (As an alternative, the original photographic recording may be preserved in the form of prints for interpretation outside the system and application of the interpreter's results to the data recorded in the system.)

When the manipulated and recorded data can be correlated with a preinterpreted form (as in the case of machine-tool and quality-control applications), no human interpretations are required and the entire sequence of operations from master to replica may be automatically performed.

Since all the data to be manipulated must pass through the interrogation process near the beginning of the system, it appears that design and implementation of operational automatic interrogation equipment is crucial to the development of the optimum photogrammetric data-reduction system. Some important and fundamental work has already been done in this area, both by private and by Governmental mapping and engineering organizations concerned with increasing productivity in the field of stereophotogrammetric reductions of aerial photography. The most promising developments to date appear to be those of Gilbert Hobrough in Canada and Paul Rosenberg in the United States. Mr. Hobrough's automatic scanning correlator for anaglyphic stereo-models (the Stereomat) is expected to automatize much of the interrogation and recording function for the fixed focal-length, standardized format photography for which it is designed; and in combination with automatic recording elements presently being adapted to its principle by Benson-Lehner Corporation for the U. S. Air Force, may be further developed for use with other types of photography and projection. Mr. Rosenberg's digital data system for recording and reducing photogrammetric information about the earth (PHOTOGRAMMETRIC ENGINEERING, Vol. XXI, 4 and Vol. XXII, 5) appears to offer a promising start in the direction of automating the data reduction process for many applications of aerial photogrammetry, and will be watched with profit by everyone concerned with the advancement of this field.

Existing stereophotogrammetric instruments usually employ the simulator principle, in that optical and mechanical reproduction of the positions of photographs attempt to recapture the projective relationships existing at the moment of exposure of each photograph. Where rigid restrictions on the size and optical characteristics of the camera used can be enforced without seriously limiting the system utility, relatively inexpensive instruments of this type yield quite satisfactory results. Where more versatility is required, the cost of instruments can increase quite rapidly, as evidenced by the so-called "universal" plotting instruments available today. Automatic interrogation can be applied to most, if not all, such simulator instruments, and automatic recording can almost certainly be applied to the output of the automatic interrogation applied to these instruments. However, the ultimate accuracy of even the finest and most costly simulator systems is limited by the deviations from theoretically exact projection which are always present in these instruments as a class.[1] To obtain an increase in theoretical accuracy with versatility and reduction in instrumental bulk, *mathematical* projection systems in which image-point ideal positions are computed, instead of being physically reprojected, appear to offer high potential benefits.[2] The adaptation of some of these principles is being undertaken in at least three different countries today, and it appears safe to predict that the photogrammetric data reduction systems of the future will embody mathematical projections, in whole or in part, in their interrogation and transformation operations.

It should be recalled at this point, however, that we are dealing with the interrogation of an energy continuum, in all photogrammetric processes; and attempts to reduce this continuum to symbolic form must be very carefully planned if we are not to filter out and lose valuable information, on one hand, or overwhelm the symbolization process with data on the other. Since digitization is symbolization, it is highly probable that the digitization of photogrammetric information should be applied only after the interpretation and filtering processes (human operations) are complete. Where most of the data can be predicted in advance as not important to the decisions desired, as in the case of some engineering applications of aerial photography (notably some special cases of highway location, for example), the symbolization-digitization may well be ap-

[1] "New Principles for Photogrammetric Plotters"—Prof. U. V. Helava, October, 1957 Report of the National Research Council of Canada.

[2] Ibid.

plied quite early in the system, even during the interrogation phase of operations. Where, however, the end use to be made of the data contained in the photographic sensings is not so certain, or so rigidly defined, it is likely that early digitization will either overwhelm the system* or will require human selection and elimination at the start of much of the information contained in the photographic sensing, to avoid this saturation of the digitization process. Wherever the totality of end decisions, and the data required to render them valid, cannot be predicted with certainty in advance, early digitization of the information is certain to result in loss of valuable information which was available in the photographic sensing of the analogic energy continuum. In the great majority of photogrammetric data systems, therefore, it appears valid to assume that the economically feasible machine operations of manipulation, transformation, and recording to provide the store of pre-reduced data for human decisions should use analog processes and not digital reductions—that is, should stop short of symbolization, or postpone symbolization to the end of the process (at the human decision stage).

* (E.g., with the best present-day data recording system using high-density magnetic tapes, a single 1/10,000 stereo-model using 6-inch focal length, 9×9 inch photography, contains enough digital information if interrogated only at 0.1 millimetre intervals to fill over 17,000 feet of tape—representing a major filtering of the data which was originally contained in 162 square inches of photographic film—a multiplication factor of more than 700 times in area of medium for recording, with a loss in information content as additional penalty.)

With the implementation of the optimum photogrammetric data reduction systems embodying the maximum of economically feasible automation principles, we may within a few years hope to close the existing gap between our ability to obtain photographic sensings and our capacity to process these sensings into meaningful information for human decisions. Ultimately, perhaps, the sensor and the data reduction systems will be combined, and processed information will be transferred directly to the decider, with or without intermediate stops in an information storage medium. The basic operations of sensing, interrogation, manipulation, measurement, transformation, recording, filtering, and interpretation will still be found even in this advanced state of photogrammetric information processing—and the same machine and human functions may be expected to still apply.

The earth, and all that is material in the universe, are three-dimensional analogs. Photogrammetry is the use of light energy to obtain and manipulate information about these analogs, so that reasoned decisions can be made with a minimum of material manipulation. When photogrammetric systems are fully designed to take advantage of their potential—that is, when *actions* involving matter are preceded by manipulations of *information* about matter, to the extent which photogrammetry *can* provide, we shall have attained our majority.