SOME NEW CONCEPTIONS AND OLD MISCONCEPTIONS OF PHOTOGRAMMETRY

By Charles L. Miller*

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Introduction

During the past ten years, we have heard and read many papers and articles about what photogrammetry can do and how it can be applied to civil engineering as a method of mapping. The emphasis has been primarily on the value of photogrammetry with little effort expended on explaining the subject to the engineering profession. The purpose of this paper is to present some simple basic concepts and to correct certain misconceptions.

The Misconceptions

Engineers have a number of common misconceptions of photogrammetry. Some of these include: photogrammetry is

(1) Relatively new
(2) Only applicable to map making
(3) Not very precise
(4) Only applicable to "preliminary" engineering
(5) Rather mysterious
(6) A minor professional field
(7) Conducted only by technicians

The reason for these misconceptions is principally due to a reluctance on the part of the engineer to take the time and effort to obtain a basic understanding of the subject. As with most technical subjects, although the details are many and the ramifications complex, the basic fundamentals are few and simple. The full potential of photogrammetry has hardly been realized and is being retarded by a lack of common understanding and appreciation for the subject.

*Assistant Professor of Surveying, Massachusetts Institute of Technology, Cambridge, Mass.

A Basic Definition

Photogrammetry is defined by the American Society of Photogrammetry as "the science and art of making measurements with photographs." It is noted that this definition does not limit us to any one type of photography such as aerial photography nor to any one field of application such as map making.

Photogrammetry is essentially a method of making space measurements. Therefore it is not necessarily a separate field of endeavor divorced from engineering and surveying, but rather a tool to be utilized by all who require space measurements.

The engineer readily accepts soil mechanics as a tool to assist him in the design of his structures. He should also accept and study photogrammetry as a tool to assist him in the planning and design of his projects. In both cases—soil mechanics and photogrammetry—the expert has his place. But also in both cases the potential value of the fields will only be realized when each engineer has at least a basic understanding of and appreciation for the subjects.

How New

Although photogrammetry has experienced its greatest advance in application and acceptance in the United States during the last ten years, its development dates back over a century. Some of the principles of the science of measurement with pictures date back to the early 1700's before the discovery of photography.

Laussedat, the Father of Photogrammetry, first used the photographic camera for space measurement in 1851. The forerunner of our modern stereoplotters appeared about 50 years ago. Photogrammetric surveying by private firms in the United States is about 35 years old. Photogrammetry is therefore not something new but a method of measurement backed by over 100 years of active scientific development. It is new only in the sense that it is still in the process of coming to the attention of some of our engineers.

A Basic Concept

If we consider photogrammetry as a means of creating a spatial model of the object photographed and as a means of measuring this model, one can easily comprehend how it can be applied to a tool of space measurement. This simple concept of the method removes much of the mystery—we merely create a model and measure the model instead of the actual object. It is therefore applicable to anything that can be photographed.

Where Used

We can say that photogrammetry as a method of space measurement can be used to advantage anywhere it would be difficult and uneconomical to directly measure the actual object. For example, photogrammetry might be applicable if the object is:

(1) *Very large*—such as a portion of the surface of the earth.
(2) *Very small*—such as sand grain or roughness of a metal surface.
(3) *Moving rapidly*—such as a structure under dynamic loading or ballistics missile.
(4) *Changing rapidly*—such as a hydraulic phenomenon.
(5) *Inaccessible*—such as a moving dust particle in a furnace or atomic particle in a cloud chamber.
(6) *Complicated*—such as a deformed structure or the human face.

In the light of this concept—if it is difficult and uneconomical to directly measure the object, create a model of the object and measure the model—the unique uses of photogrammetry periodically reported are not so amazing but are natural applications.

Photography and Stereovision

A photograph is a perspective projection of the object photographed. It is a graphical record of a set of directions. In a perspective all of the rays from the object converge to one point. A perspective projection is the trace of the intersection of these converging rays with a plane located between the object and the point of convergence. The basic difference between photographic surveying and conventional surveying is that in one case we measure angles with a transit, and in the other with a camera. The photogrammetric camera may be thought of as an angle recording instrument. The human eye sees essentially a perspective projection. We are able to perceive depth because each eye sees a different picture. The eyes essentially triangulate distances—the distance between the eyes being the baseline. Points appear different distances away because they form different angles opposite the baseline. This angle is called the angle of parallax and is a measure of distance.

If we replace the eyes by cameras and record photographs of what the eyes would see, and then place the photographs in their proper position in front of the eyes, we would perceive the identical result as directly viewing the object photographed. Hence we can duplicate natural stereovision by means of photographs. Since the angles of parallax exist in both cases, we can perceive and measure depth by means of photographs. Essentially we require two photographs of the same object taken from different camera positions.

Creating the Model

When the photograph was formed, rays came from the object to the photograph. If we return to our camera position with a projector (which reverses the direction of the rays) the rays will return to their point of origin on the object. Similarly, if we have a second projector projecting the photograph from a second camera position, the rays from a given image point appearing in both photographs will intersect in space at their point of common origin. Under these conditions, we will project a three dimensional model coinciding in space with the original object.

If we hold the two projectors in their relative orientation, but move them closer together, the rays from common image points will continue to intersect in space but will form a smaller size model. The ratio of the distance between the projectors to the distance between the camera stations is a measure of the scale of the model formed by the spatial intersection of the rays.

The spatial model formed by the projectors cannot be perceived by the unaided eyes. As mentioned before, each eye must be presented with a separate and different picture. Therefore, one eye is only allowed to see the picture from the first projector and the other eye is only allowed to see the picture from the second projector. When this is done, the mind will fuse the two sets of images into the spatial model which appears as real to the mind as viewing a physical object.

The Fourth Dimension

In addition to the three linear dimensions of x, y, and z, the spatial photogrammetric model has an important fourth dimension—time. Our model is a true replica of the object photographed at a specific instance of time. This fourth dimension is the most important element in many types of problems. For example, if the object is moving or changing rapidly here is a method of freezing its exact shape, size and space location at any selected time or intervals of time for later measurement and study in the laboratory.

The object does not necessarily have to be moving or changing rapidly. The movement of glaciers and the settlement of large areas of terrain over a period of time (such as in the Los Angeles area) have successfully been measured by photogrammetry.

The Need for Control

We previously stated that a photograph is only a means of measuring or recording angles. In triangulation, we know that we require the length of at least one side of a triangle (a baseline) in a network of triangles before we can compute the triangles. Angles alone do not define size. The same is true in photogrammetry. We have to measure at least one distance in our system in order to determine size or scale of the model.

A second basic requirement in any surveying system is horizontal orientation. What are the directions of our lines with respect to our space framework reference axes? Here again, as in ground triangulation, we need the horizontal orientation of at least one line in our model. These first two requirements, scale and direction, can be satisfied by having two points in the model of known horizontal position. The distance between the two points establishes scale and the bearing of the line between the two points establishes direction.

A third consideration is the establishment of a datum plane. Since it takes three points to determine a plane, we need the differences in elevation between three points in the model to define the datum plane. If we are compiling a topographic map and would like our elevations referenced to our standard datum, we would need the mean sea level elevation of one of the three points.

In summary, to locate our model within some established space framework, we would need at least two horizontal and three vertical control points located within the model and referenced to the desired coordinate system.

We have spoken so far about an individual model formed by two photos, say A and B. However, photos B and C, C and D, etc., may form additional models which together form a continuous model of a large area. The individual models can be compared to individual triangles in a triangulation system. If we know everything about one triangle, we can compute the location of the rest. Similarly, if we have oriented, scaled, and referenced one of the individual models, we can determine the space location and all the points therein of the other models. Just as with ground triangulation, we can only continue this process of aerial triangulation until our error accumulation becomes too large. The important point is that we do not necessarily need "outside control" in every individual model.

Measuring the Model

The ultimate goal of most of our conventional surveying operations is the x, y, z coordinates of selected points, the graphical record of the xy position of selected lines, and the representation of relief by contour lines. In our photogrammetric method, once we have created and oriented our model, we achieve these goals directly without any intermediate measurements, computations, adjustments, or plotting. How this is done may be understood if you visualize that within the spatial framework of the model, we insert a reference mark in our instrumentation system such that it can be freely moved in model space, and such that its model space position is always known. (How this is accomplished may easily be demonstrated mathematically or graphically but we are dealing here with concepts and not technical theory.) With this movable and calibrated reference mark, we have the perfect surveying tool. This may be likened to the surveyor having a little black box with three dials that always indicate the x, y, z's of the box as it is carried from point to point. To trace the plan position of a line, we merely move the index along it. To run out a contour, we set the z value of our reference mark to equal the elevation of the desired contour. The mark is then moved until it touches the surface of the model. This is one point on the contour. Now if the mark is moved but constantly kept in contact with the model, we are tracing out the desired contour. A pencil point is coupled with the reference mark so that our point, plan line, or contour line is automatically plotted.

The Stereoplotter

There are three common approaches to solving engineering problems: (1) analytical or mathematical (2) graphical (3) mechanical. By mechanical we mean with a machine or instrument. Most photogrammetric problems may be solved by any one or a combination of these approaches. For carrying out the concepts previously presented and in actual practice, we find the third approach to be the most feasible.

The stereoplotter is the most basic and important instrument of applied photogrammetry. The stereoplotter is an instrument for creating and measuring the spatial model and recording the results. Practically all work in applied photogrammetry revolves around the use of this instrument. In addition, much of our theoretical and research in photogrammetry work is concerned with stereoplotters.

A stereoplotter consists essentially of (a) two or more projectors or other means of forming the spatial intersections, (b) facility for moving these projectors along and around three mutually perpendicular axes to reconstruct relative and absolute orientation, (c) means of separating the projections for the eyes, (d) a movable and calibrated reference mark, and (e) a plotting system.

A stereoplotter represents one of the highest forms of precision optical and mechanical instrumentation built by man. Although they all perform basically the same function, there are a number of different types and makes of stereoplotters available to the engineer and scientist. The commonly used plotters in the U. S. include the Bausch and Lomb Multiplex, Kelsh Plotter, Wild Autographs (Swiss), and Zeiss Stereoplanigraphs (German). Last year Bausch and Lomb introduced a new stereoplotter trade named the Balplex. Other important stereoplotters include those of Pivillier (French), Santoni (Italian), and Nistri (Italian). These instruments range in cost from approximately $4000 to approximately $75,000.

How Precise

All measurement systems and their instrument components contain certain sources of error. We therefore design our measurements in such a way that we can (1) reduce the errors to a tolerable level (2) correct for the errors by instrument design or measurement technique, or (3) make secondary measurements to enable us to compute the errors and correct the primary measurement. Of course we never completely eliminate errors but reduce the total error until we obtain the desired precision.

In this respect, photogrammetry is no different from any other measurement system in that it contains many sources of error. However, the photogrammetric engineer can reduce, correct, or compute these errors and so design any measurement project to obtain the desired precision.

In the convenience of the laboratory, we know that we can measure to 1/1000 inch with several common instruments with relative ease. In the drafting room we measure and plot points to the nearest 1/100 inch with a good engineers' scale. Therefore, measuring and plotting small increments of space is not unusual in the laboratory. Previously we presented a concept of photogrammetry as the creation of a spatial model of the object photographed and the measurement of the model. The precision of the method then involves how precisely we can create the model and how precisely we can measure it. The precision with which we can create and measure the model depends on many factors such as the camera, flight height, control, the stereoplotter used, human element, the nature of the object, and the design of the over-all system. Errors originate from these and many other sources. What is important is the value of all of these individual errors at the scale of the model. For example, in a modern well designed photogrammetric system, the total error at the scale of the model might be of the order of 6/1000 inch or 0.0005 feet. We therefore present a concept that the precision of our photogrammetric measurements is a function of the size of the model. For the conditions of our example, we could set up a table as follows:

If the Allowable Error Is	We Need a Model to a Scale of
0.0001′	1/0.2
0.0005′	1/1
0.001′	1/2
0.01′	1/20
0.1′	1/200
1′	1/2,000
2′	1/4,000
5′	1/10,000
10′	1/20,000
20′	1/40,000

In essence, the higher the precision, the larger the model for a given photogrammetric system. If measurements to 1/10,000 foot are required, we need a model five times the size of the actual object. If measurements to 10 feet are required, we can use a model 20,000 times smaller than the object photographed.

The error in running a contour line is about twice that of a discreet point. Since the allowable error in a contour is one-half the contour interval, the model sizes given in the table above must be multiplied by four if the numbers in the first column are contour intervals. For example, two foot contours would require a model scale of approximately 1:1,000.

It is obvious that there is no inherent limit to the precision of photogrammetry. In fact, with microphotogrammetry, measurements to the order of microns at the scale of the object are entirely feasible. When people speak of limits for the precision of aerial photogrammetric mapping, they really mean there are minimum practical operating limits on the altitude of an airplane.

Photogrammetric engineers work in terms of the measurement precision being a function primarily of the flight height or object distance. However, it can be shown that the concept of precision being a function of model size is compatible with other approaches and is presented primarily because it is easy to visualize.

Photo Analysis

In this paper, we have dealt entirely with basic concepts of the measurement aspect of photogrammetry. In addition to recording angles, the photograph records an infinite amount of qualitative information. Therefore, photo analysis and photogrammetry are closely allied but somewhat separate fields of endeavor since the areas of knowledge involved are quite different. Mathematics and physics are basic to the photogrammetric engineer whereas geology and agronomy are more important to the air photo analyst.

The nature and extent of the information and data which the highly trained professional photo analyst can obtain from aerial photos borders on the fantastic. Soils, drainage, geology, land classification, vegetation, human activity are only a few of the many areas of data that can be obtained.

It is not within the scope of this paper to discuss the qualitative aspect of photography but it is important to note the distinction between the work of the photogrammetric engineer and the photo analyst.

The Photogrammetric Profession

The final two misconceptions to be discussed are the size of the field and the type of people involved. For some time, we have lacked accurate factual statistics on the size of the photogrammetric activity in the United States. This is the subject of a current study at M.I.T. We feel this study will be quite revealing and establish that photogrammetry is a major field of professional activity.

It is true that photogrammetry utilizes a large number of technicians just as most professions do. We might compare a photogrammetric project with building a bridge. Just because the actual labor of building a bridge is handled by a large number of "technicians" and construction workers does not mean that no engineers are involved. Similarly, the fact that technicians furnish the labor in a photogrammetric project does not mean that engineers are not involved in planning, designing, and constructing the project. The professional engineer and scientist is as essential in photogrammetry as any other professional field. The tremendous advance and technical development of photogrammetric methods and instruments in recent years is sufficient evidence that a large number of high level engineers are hard at work in photogrammetry. Research activities alone occupy the services of a very large number of engineers and scientists.

The civil engineer educated and trained in photogrammetry has before him one of the greatest challenges to explore and develop new frontiers available to the professional man.