One phase of the Soil Erosion Service mapping program not referred to above relates to the construction of contour maps. The photographs taken of the Navajo survey are adaptable for use in the Stereoplanigraph for the construction of such maps. At the time of issuing the advertisement, it was not known whether any such contour maps would be needed. However, it developed that such a map was necessary to the functioning of the Mexican Springs Experiment Station, just north of Gallup, New Mexico, which is working on detailed scientific studies covering a watershed of some 128 square miles. This map was recently completed and is discussed in Mr. Leon T. Eliel's article in this issue of "News Notes".

THE STEREOPLANIGRAPH

by
Leon T. Eliel

(Paper presented at meeting of the Society on October 23, 1934)

Any photogrammetric machine such as the Stereoplanigraph is merely the mechanical means for recording what the eye sees, what the brain conceives, and directs the hands to perform. The machine is designed around these human factors and a proper evaluation of the machine must have roots in a thorough understanding of these human elements.

On first thought, the stereoscopic function of the eyes seems quite apparent. Obviously, we think the closer an object, the greater the convergance of the eye axes. This, we assume, is interpreted by our brain in terms of relative distance.

It is commonly believed that when using a stereoscope, an object appears at the point of intersection of the eye axes. Diagrams illustrating this phenomenon are plentiful throughout the literature on this subject.

That this situation is much more complicated than suggested by these random thoughts is at once brought home to us when we see a trained stereoscopic observer view a pair of pictures without a stereoscope under conditions where the axes of the eyes actually diverge 10 or 15 degrees. Where, now, does this observer see his apparent stereoscopic image? If our first theory were correct, the imagine would appear to be behind him. This, we know, is not true. It is therefore safe to assume that stereoscopic vision is a much more complicated subject than appears from casual inspection.

When the axes of the observer's eyes are diverging, one of two things must be occurring to enable him to see stereoscopically. Either the brain is exercising some marvelous interpretive power quite beyond our comprehension, or what is more probable, the lens of the eye is willfully distorting into a prismatic shape. The latter assumption seems borne out by the fact that ability to view pictures stereoscopically with divergent eye axes is greatly enhanced with practice. Furthermore, this ability is acquired only with difficulty, if at all by persons of advancing years. Young men acquire the habit readily enough, all of which gives substance to the theory that the muscles of the eye may be trained to form a prism of the lens of theeye.

For this reason, it is desirable that stereophotogrammetric operators receive some training before reaching the age of 40, in order to acquire a keen sense of stereoscopic perception. The eye, which is going to spend its life in optical gymnasium, should obviously acquire its training for the task gradually.

It now becomes apparent why it is not possible for a middle-aged or elderly person, who has had no stereoscopic training, to operate photogrammetric equipment with the same degree of skill as someone trained for the job. I do not mean for a moment to suggest that a photogrammetric operator must be a superman in any sense. He should, however, have had a considerable amount of specialized training before he calls upon his eyes to serve him in this capacity.

The proper functioning of our machine then, is predicated upon a pair of well-trained eyes.

Depending upon the nature of the map which is to be drawn, rests the question of whether the function of the brain is merely to transmit to the hands the properly coordinated action to what the eye sees, or whether some interpretive editing is to modify the exact situation revealed by the eyes.

To illustrate: Case No. 1 - A detailed large-scale map of a dam site strictly for engineering purposes. Obviously in this case, no interpretation is required on the part of the brain. The contour should follow every feature of the ground with mechanical precision. Case No. 2 - A small-scale map for general use. Here, physiographic form becomes important and ease of interpretation by the lay-user, is a feature. At the moment, the subject of the amount and degree of modification of the contours which is justifiable to emphasize physiographic form and make the map easier to read is a highly controversial issue in many quarters of Washington. It seems reasonable that in the ordinary type of quadrangle sheet, some sort of compromise must be struck between mechanical precision and a map generalized for ease of reading. If it were definitely known whether these maps are used principally by layment, physiographers, or engineers, the question of the amount of detail which should properly be shown could be answered with some certainty.

How much then the brain should interpret and edit what the eyes see in a photogrammetric machine is a question of judgment on the part of the map-maker as to what constitutes the best quality of map for the purpose intended.

It is the belief of some proponents of the more mechanical contour, that an original line drawn with full detail and every wrinkle is desirable in that it gives practically a perfect foundation. In preparation for reproduction, the topographer may then exercise as much judgment as he deems necessary in smoothing out the contours. In this editing, he will undoubtedly be guided by the purpose for which the map is intended.

The impression that all photogrammetric contours are ragged and represent inaccuracy or uncertainty on the observer's part is definitely proved to be fallacious by a study of many photogrammetric maps. Where the ground is smooth, photogrammetric contours are equally smooth; where the ground is ragged and wrinkled with many boulders and irregularities, so are the photogrammetric contours.

It is only necessary to decide what constitutes the best average cartographic practice and the photogrammetric method can easily be made to conform.

In addition to the skill of the eye, the judgment of the brain and the coordination of the hand of the operator, there are certain fundamental physical principles which play an important part in the success of any photogrammetric method. First, there is the base line influence. Just as the accuracy of traingulation is improved by strong intersections, so is the photogrammetric accuracy increased by a favorable base altitude ratio which amounts to the same thing. There are, however, two limiting factors which tend to nullify the advantages of the base altitude ratio when carried beyond a certain point. The first and most obvious factor is the blind spots which will occur in steep country when the base line is too long and the angles consequently too flat. The second factor limiting the length of the base is that of haze. If the atmosphere could be considered perfectly clear, this factor would be negligible. Whenever there is sufficient haze so that the definition at the edges of the picture begins to suffer, a loss of accuracy will result which may entirely offset the advantages of the increased base. Naturally, the amount a base may be extended advantageously will differ in accordance with the local haze conditions. The worst haze conditions which will probably be encountered is therefore the limiting factor in determining the most favorable base altitude ratio.

Another physical element which enters into the ultimate accuracy of the method is the size of the image in relation to the size of the photographic grain. Other things being equal, it would seem that the longer the focal length and larger the scale in relation to the grain, the more accurate the observation. Some authorities on this subject have expressed the opinion that the longer the focal length, the greater is the appreciable blurring effect due to speed of the airplace and angular movements of the camera. Whether or not this is an actual factor is somewhat controversial. During an exposure of 1/100 of a second, an airplace moving at the rate of 100 feet per second will obviously move one feet and the imagine will blur one foot, regardless of the scale at which that one foot may be recorded. Similarly, angular movements will give exactly the same absolute blurring in feet, quite regardless of the scale of the image. It has always seemed to me that it is advantageous to increase the focal length of any photogrammetric equipment to a point where the mechanical problem of handling such large negatives in a plotting machine becomes difficult. With the rapid progress occurring at the present time, tending to minimize grain effect, we may anticipate in the near future that the size of photogrammetric equipment may be decreased without sacrifice of accuracy.

The third limitation which justifies consideration is optical. Of primary importance in any photogrammetric method is the photographic quality of the imagine from which measurements must be made. This photographic quality resolves itself into several considerations. First is the all-important subject of lens definition. Our lenses must all be a compromise, as we could almost invariably secure better definition from a slower lens of less aperture. On the other hand, this would limit the depth of filters it is possible to use. Therefore, our lenses must be a good compromise between actual lens definition and sufficient speed to permit the use of adequate filters. Recent increases in the speed of our photographic materials have greatly simplified this problem.

Naturally, the most careful processing must be used to preserve the fine photographic quality which we achieve with a proper selection of our lenses, filters and photographic materials. Many a potentially perfect picture is recorded at the instant when the shutter snaps, only to be ruined by a developing process which kills the beautiful quality of the exposure and brings the grain up to a point where it becomes a positive menace to photogrammetric plotting.

And now we come to the consideration of a particular plotting machine analyzed not only from the standpoints of its optical and mechanical structure, but also from its adherence to these other principles which we have discussed.

The Stereoplanigraph is fundamentally the simplest of all photogrammetric plotting machines. Those who have seen it may recall a veritable maze of wheels, rods and "gadgets" which appear anything but simple. Yet this machine is a perfect replica in miniature of the situation by which the pictures were originally secured. Of course, in plotting the process is reversed. The rays of light instead of originating on the ground to be gathered in by the photographic lens and recorded on the negative, originate at the negative and are projected back by the lens to the "ground". The two exposures constituting one stereoscopic pair project simultaneously, and after the conventional stereoscopic adjustment and horizontalization has become perfected, the two rays of light, which in the Stereoplanigraph originate at the two images of any given point, will intersect at the point they represent on the "ground" of the Stereoplanigraph. At any given instant, we are only interested in one point on the ground, that is we construct our contour line as a continuous series of points. So in the Stereoplanigraph, we represent the ground by only a point - a physical dot on the surface of a mirror which, for all practical purposes, may be visualized at the intersection of the two rays of light from the images representing this ground point. Actually and for mechanical reasons, it has been necessary to spread our two cameras too far apart on the machine to represent a perfect miniature, and this is taken care of by supplying two "ground" dots which are separated by the same amount as the cameras. Theoretically, a further separation should occur between the cameras, equal to the length of the air base at the scale of our plotting. Actually instead of separating our cameras, which are bulky, we mount them rigidly and move our two dots closer together by the same amount which has the same effect as moving the cameras apart. This difference in the separation of the "dots" or ground point of floating mark as it is usually called, and the separation of the cameras, represents the separation between the points of exposure in the air times the scale of the map expressed as a representative fraction.

Having the two dots on two mirrors permits the stereoscopic observation of the image. Each mirror turns the light from its camera into an observing system which transmits the image to the binocular eye piece. No attempt will be made in this article to explain how the dot enables the observer to draw a contour line. For this purpose, the reader is referred to the article by C. H. Birdseye and discussion by E. R. Polley and the writer in the Proceedings of the American Society of Civil Engineers of April 24, 1930.

The Stereoplanigraph has an optical system of great clarity which enables the eyes to view the stereoscopic image with the axes nearly parallel. The optical system permits the observer to see the image under the greatest practical magnification in consideration of the grain and other factors. Under proper conditions of magnification and with the axes of the eyes approaching parallelism, it has been found that stereoscopic perception is probably as much as 14 times greater than it would be when observing the same pictures in an ordinary mirror stereoscope.

The Stereoplanigraph when used with a fourcouple camera has a most favorable base altitude ratio of approximately 2:3.

The focal length of the fourcouple camera has been largely governed by considerations of the size and weight of the aerial camera. The equipment is just about as large and heavy as can be conveniently carried in the ordinary commercial airplane. The lenses of this camera are Zeiss Orthometer of about 5.3" focal length. They are designed to work at f4.5 and give satisfactory definition. Experience indicates that loss of definition occurs from grain effect and imperfect processing rather than lack of definition on the part of the lens.

The Stereoplanigraph eliminates substantially all mechanical translation between the floating mark or "dot" and the actuating mechanism of the instrument. These articulative movements have proved detrimental to the accuracy of the work done by machines of earlier design. The fact that on the Stereoplanigraph the floating mark rests physically on the surface of a mirror, onto which the image is directly projected, practically eliminates all possibility of mechanical error, other than in the plate holder itself. In this plate holder lies one of the principal problems of the Stereoplanigraph, which did not occur in earlier models. With four separate pieces of film in each plate holder, or positive plates made therefrom, there is a slight differential in film size which tends to change the angles of projection. It is obvious that if the film has expanded, the focal length must be slightly increased to maintain the same angle at the lens. During the period of the Bushkill tests, a considerable amount of difficulty was encountered because the method for determining the focal length was not sufficiently accurate. The result was that after carefully adjusting the four pomponent plates of one exposure group, there would be a pie-shaped slice or gap left in the seam between plates A and D. In other words, when the focal length was not exactly right and after adjusting B to A, C to B and D to C, there would be an overlap or shortage in the match between A and D. It was found possible to minimize this by an extremely tedious process of adjustment, although it is doubtful whether the difficulties resulting from this error were entirely eliminated prior to the completion of the tests of the Bushkill Quadrangle, Pennsylvania. There was an inclination on our part, when we failed to hit the control on the Bushkill Quadrangle, to question the accuracy of the control. A checking over of the control by Mr. R. L. Wilson indicated very satisfactory closures and discounted any possibility of the control being in error.

At the beginning of plotting the Mexican Springs, New Mexico, topography, which was entirely controlled by triangulation, we experienced some of the same difficulty which had prevailed throughout the Bushkill demonstration. At this stage of the proceedings, we commenced making a precise determination of the film shrinkage by measuring the distance between the registration points of each plate to .01 mn. This at once eliminated all of the difficulty which we had been experiencing by making it possible to compute the focal length and set it for each plate at the time of placing the plate in the machine.

After eliminating these difficulties, the Mexican Springs topography went together with remarkable speed and accuracy. The average time of adjusting the last dozen plate pairs for plotting was less than 4 hours and the control, of which there was frequently as much as 8 points on a single stereoscopic model (by stereoscopic model is meant the area which is common to a pair of overlapping exposures), was met without appreciable error both horixontally and vertically. In photogrammetric plotting, one single stereoscopic model in the middle of a job frequently has contours connecting with a half-dozen surrounding models. When these contours connect all within the specifications of the job, it is even a more convincing demonstration of the accuracy of the work than meeting a number of control points.

The last half of the Mexican Springs topography was turned out on the Stereoplanigraph at the rate of one square mile per each two hours, complete. The necessary control cost was approximately $15.00 a square mile. Add to this the depreciation and amortization on the equipment and the time of an operator and assistant for two hours, and you arrive at a cost per square mile. If this equipment were used by a Government agency and operated at its maximum effectiveness, maps could be made to the existing standards in all but flat or densely timbered country at not to exceed one-half of the present cost. This statement is based on maps at a scale of 1:24,000. As the scale gets smaller, the methods obviously approach each other in efficiency. It is, however, practically certain that within a year or two, 30,000 feet airplanes will be available which fly at high speeds, at which time the photogrammetric method will result in a tremendous economic advantage, even at scale of one inch equals one mile and smaller.

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DISCUSSION OF MR. ELIEL'S PAPER
by
W. N. Brown

I am sure that all of us who have had the opportunity of hearing Mr. Eliel present this paper have had our faith in the efficacy of photogrammetry as means of making topographic maps, strengthened. I hasten to express my appreciation of the service he has rendered. Certainly the map of the Mexican Springs area which he has exhibited for our inspection is most impressive and shows a wonderful amount of topographic detail and expression. I feel also that those of us who have examined the Stereoplanigraph intrument itself must want to pay tribute to the mechanical skill and the profound thought that has brought about its production.

Since I am on the wrong side of sixty years of age, Mr. Eliel's remarks concerning the optical gymnastics required of the eye of a Stereoplanigraph operator intrigued me very much, and I am afraid that I have spent far too much time trying out the ability of my own eyes. The results may be interesting if not instructive. I find that the stereoscopic image begins to separate when the distance between the images on the two photographs is about 3.4 inches apart. The position of the eyes were about 8 inches from the photographs. The distance between my eye centers is approximately 2.4 inches. I figure that the divergence of the axes of my eyes to be 7 degrees at the time of the separation of the stereoscopic image. If I am correct, there may be some hope for men up to sixty years as stereophotogrammetric operators.

Necessarily, it is of vital interest to learn the extent of the application of this method to serve the map needs of the engineer. Mr. Eliel in his paper deals with maps in the abstract. The application of the method in practice will have to deal with each individual type of map. The word map probably conveys a different meaning or conjures up a different picture to the mind of each person. The two maps mentioned by him were both small-scale maps with rather large contour intervals. The Mexican Springs map is on a map scale of