*Automatic Contouring**

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ABSTRACT: *A brief history of the investigations and experiments in automatic contouring by the Engineer Research and Development Laboratories introduces the major problem of image matching in two overlapping presentations. The matches are made by scanning a projected stereo model. Three methods of scanning of increasing complexity are described—profile, horizontal, and contour. The problems are presented in general terms with emphasis on the photogrammetric aspects.*

"LOOK, Ma, no hands!" It was a proud day when we were able to proclaim our success in guiding the bicycle down the street without holding onto the handle bars. So it is that, sooner or later, every stereo operator in the darkness of his booth envisions automatic manipulation of his instrument.

In 1950, while this prospect was only a vision to many, the Engineer Research and Development Laboratories at Fort Belvoir, Virginia entered into a contract with Bausch and Lomb Optical Company to study the feasibility of producing contours automatically. This contract followed some preliminary experimentation by Bausch and Lomb on a suggestion by Dr. George Harrison of the Massachusetts Institute of Technology and established the possibility of automatic contouring. With the equipment produced under this contract, however, it was possible to match successfully only artifically-produced high-contrast stereo-projected diapositives.

Further experimentation under contract was conducted by Pickard and Burns, Inc., from 1952 to 1955, and produced equipment which can contour actual aerial photography with moderate success. Currently Hycon Manufacturing Company is building for the Laboratories, Automatic Contour Plotter, Hycon Model 545.

Our approach to the problem of automatic contouring involved scanning the volume occupied by the projected stereomodel from Multiplex. The criterion for determining whether a probed point was on the surface of the stereomodel was that at such a point the detail would be identical in both of the projected diapositives comprising the model. Of course, it is not possible to match points, and the necessary extension to lines and areas of match introduced additional problems; for in regions of even moderate relief, as the area is enlarged, the similarity in detail is decreased by the effects of foreshortening.

Rather than attempting to match areas optically, it was early decided to transform the optical images into voltage time-series. This was accomplished by illuminating two photo multipliers with the light from small conjugate areas in the two diapositives, as shown in Figure 1. Here each diapositive is projected without a filter through a small slit onto a photomultiplier. These slits are scanned in the X-direction as shown in Figure 2. In the first two contracts this scanning was performed mechanically by an eccentrically scribed circle in an opaque disk which rotated directly under the slits.

The transformation from optical detail into a voltage-time series is shown in Figure 3. On the top left the left phototube

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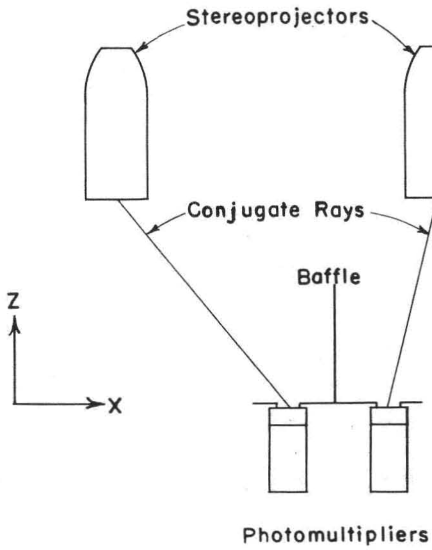

FIG. 1. Optical to electrical transformation of detail.

sees a narrow rectangular section of the left diapositive, which is essentially a line in the X-direction parallel to the air base, and below interprets the light intensity which falls upon it as a voltage varying at the rate the slit is being scanned. On the right is an area in the right diapositive with identical Y-coordinates as shown thru the slit by the right phototube and, below, its associated voltage series. The problem is now simply one of finding the Z-coordinate for each X, Y position in the model for which the detail matches; this is done automatically in the instrument by matching the voltage series from the two photomultipliers.

The method for making this match has been closely connected to the method for scanning the stereo model; in each of the mentioned contracts a different method of matching and scanning was employed: Bausch and Lomb used phase comparison matching and a profile scan; Pickard and

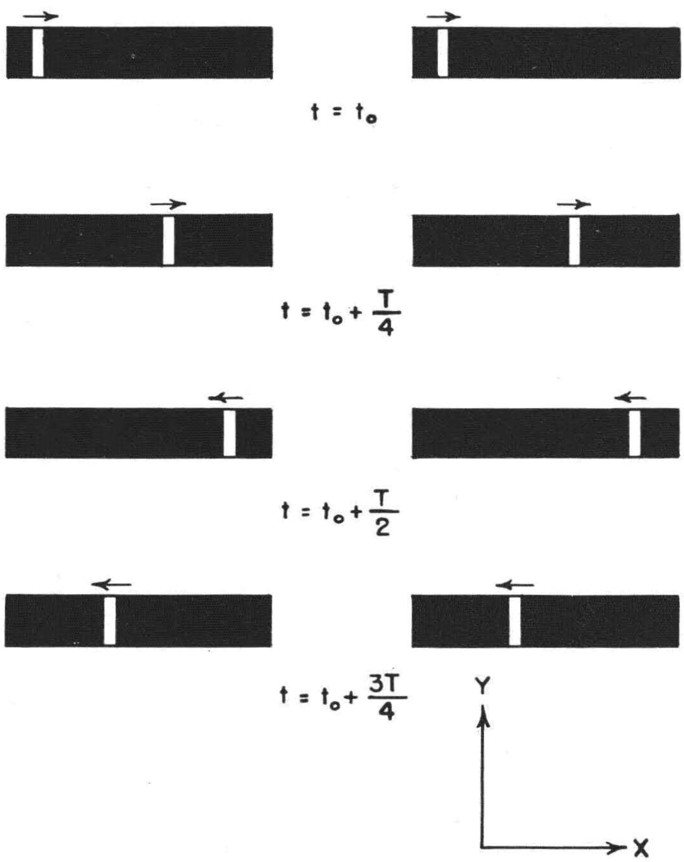

FIG. 2. Slit scanning.

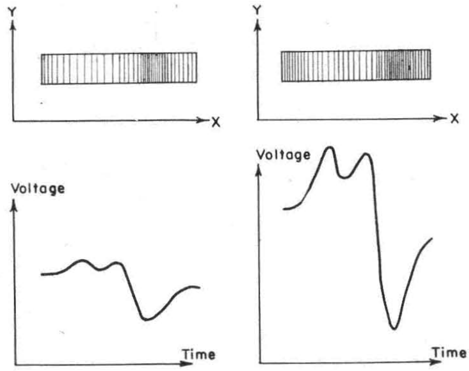

FIG. 3. Optical to electrical transformation of detail.

Burns, amplitude matching and a horizontal scan; Hycon is using area correlation and direct contour scanning.

In Figure 3 the light levels in the conjugate images were purposely illustrated as being different. This is generally the case in two overlapping aerial photographs. If a match of these two waves were attempted the result would be as shown in Figure 4. Here it can be seen that, although the detail is similar, the waves do not match because of differences in the intensity and contrast. In the early days the precision of our transducers was relatively low; because of this, an attempt to employ automatic gain control would undoubtedly have led to many false matches. Moreover, it was considered that an attempt to equalize the intensities of conjugate images by photographic means would be too complex and costly.

Accordingly Bausch and Lomb decided to use a method of phase comparison. This principal is approximated in Figure 5. Here, the average value of each curve is determined, and the points in the scan where each curve reaches its average value are compared. Later, it was proposed to determine and compare the average value crossings for several harmonics, but this extension was never made.

Phase comparison was never particularly successful, probably because it was never fairly tested, since the resolution of the first optical-electrical transducer was faulty. However, the method of scanning associated with it has always held a favored position. To scan the model in profile, the X-coordinate is fixed and the line of the slits translated in Y and Z. In this trans-

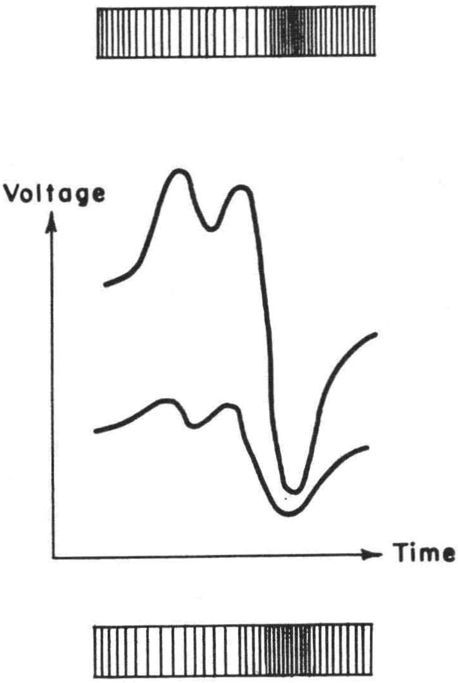

FIG. 4. Comparison of detail.

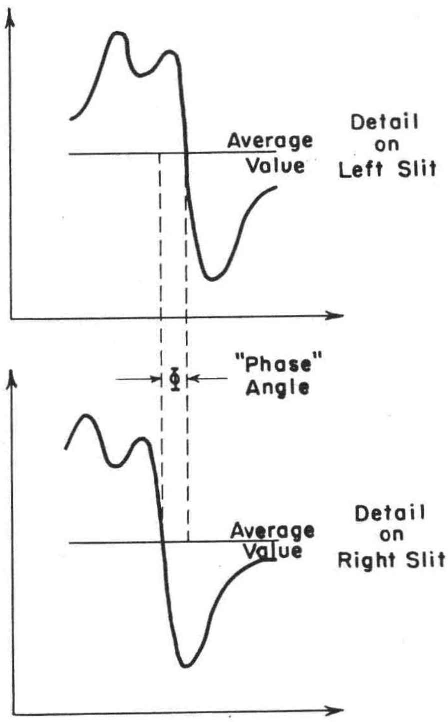

FIG. 5. Phase comparison of detail.

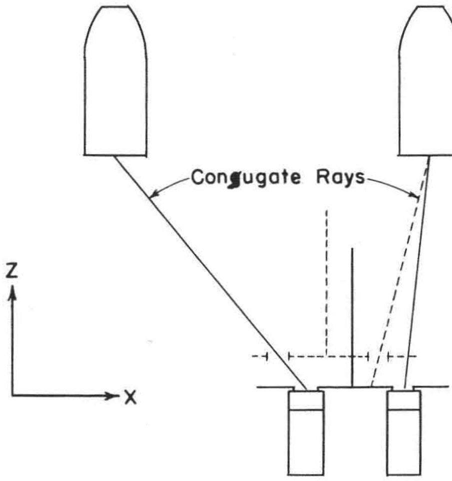

FIG. 6. Phase comparison in mismatch.

lation the Y-velocity is fixed and the Z-motion determined by the lack of correspondence in phase. Assume that the scanning unit is on the profile and begins to "dig" into the ground. Then the wave on the right, which originally was in phase with the wave on the left, will begin to lead the left wave as shown in Figure 6. As this happens, an error signal proportional to the phase angle is transmitted to the Z-motion drive, and the scanning unit is driven up onto the profile. If the scanning unit begins to float above the profile, the right wave lags the left, and correspondingly an error signal proportional to the phase angle is transmitted to the Z-motor drive, and the scanning unit is driven down onto the profile.

Thus, in the presence of clear detail, distinctive wave forms were obtained which kept the scanning unit on the profile. In the absence of such detail, the instrument would remain at a fixed level until information was made available. However, the use of the previous profile did supply additional data which helped to guide the Z-motion in the absence of photographic detail. Depending on the scale of the model, the separation of the profiles, and the anticipated maximum slope to be encountered, an upper and lower limit about the previous profile could be established between which the succeeding profile was constrained to lie. This acted as a course guide, with photo detail supplying the fine guide.

The Bausch and Lomb instrument is shown in Figure 7. The data were recorded as plastic profiles cut out with a hot wire by the Y and Z motion of the scanning unit. The cabinet contains the DC power supply, phototube control unit, the phase meter, and associated circuitry.

Going back a moment and comparing the operations of automatic profiling with those of a stereo operator, it can be seen that the automatic instrument is required to make decisions based on aerial data with a minimum of storage, while the stereo operator is able to integrate information from an area in making the decision required at a single point. Looking somewhat more closely at the phase comparison-profile scan approach, it is found that, primarily due to the heavy weight of the scanning unit, the slow response in the servo systems limited the attempt to maximize the speed of operation. In the Pickard and Burns contract, therefore, phase comparison was abandoned in favor of amplitude comparison. In order to use this approach it was necessary to introduce automatic gain control in the comparison circuitry. Thus the two waves picked up by the photomultiplier may appear as shown at the top of Figure 8 are reduced before comparison to the two waves shown at the bottom. A comparison of this sort requires that the difference of the two waves divided by their sum be less than a prescribed value. In addition, to avoid mismatches in areas of little contrast, it was required that the difference of each wave from its average value be greater than a second prescribed value.

Such a comparison, although it can be made rapidly with electronics, does not provide a direction sensitive error signal, and therefore must be made in a horizontal or contour plane. However, since there are no accelerations required in the Z-direction, the scan can be made much more rapidly. The result of scanning the complete model at a given Z-coordinate would be a sheet of indicated match points which presumably would form lines which would be the contours for that elevation. The results with actual photography have been rather 50 foot contour bands about the line indicated by human interpretation.

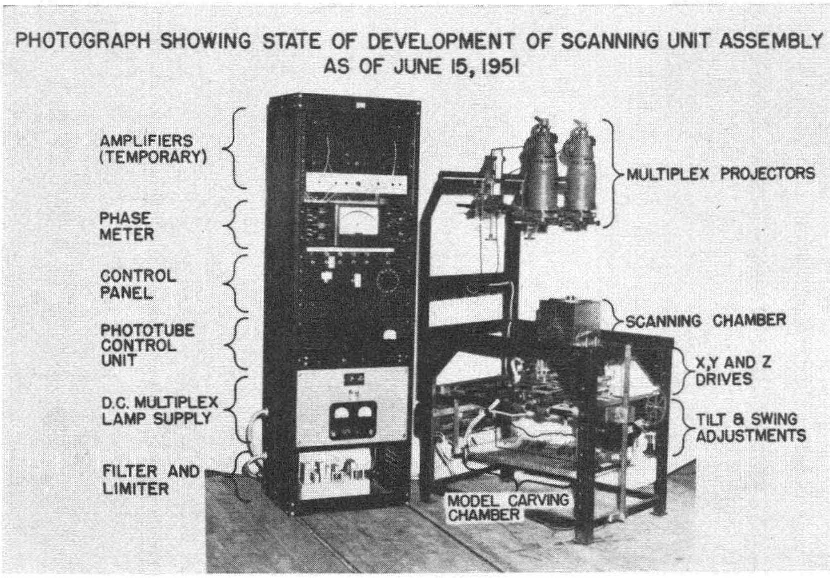

FIG. 7

The original hope was to follow automatically the contour line itself. This mode of operation is actually the goal set for Hycon Model 545, a very versatile instrument which presumably can operate both as a profile and a horizontal scanner. This operation is made possible by means of an electronic area correlation technique. Our experience with essentially line comparison of detail, made evident that in many cases there was insufficient information in a single line to determine whether or not a match really existed. The extension to an area is the natural result of this experience.

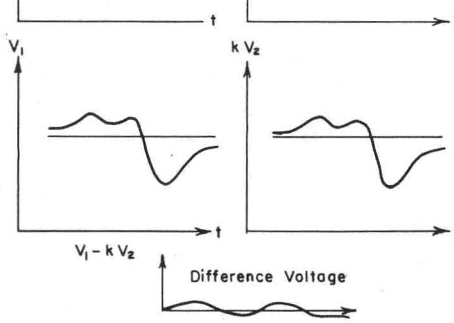

FIG. 8. Automatic gain control and amplitude comparison.

Photogrammetrically, the area correlation method may be considered as placing a small rectangle on the model at a certain elevation. By keeping Z-constant and noticing how the detail in the rectangle of one diapositive changes relative to the detail on the other diapositive as the hypothetical rectangle moves in X and Y, the rectangle may be maintained on the contour line and tangent to the model at its midpoint.

Workers in industry and the Government have expressed fear of unemployment due to increasing automation. The stereo operator who was dreaming in his booth now wrongly interprets this vision as a nightmare. The prospect of automatic contouring has advanced materially in the last six years. However, many fascinating problems remain to be solved before contouring can be accomplished without human guidance. A machine can perform only in accordance with the instructions programmed into it. It will be a long time before all the experiences obtained in a Multiplex booth can be distilled into a mass of machinery.