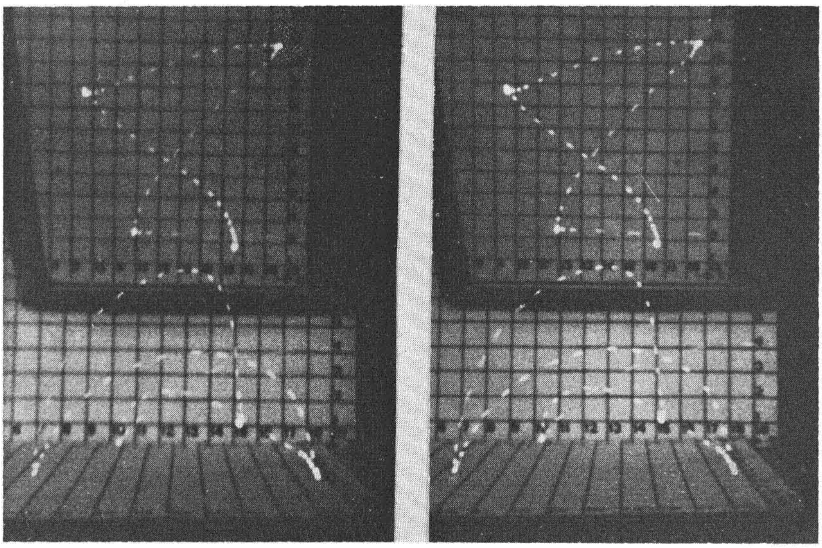

FRONTISPIECE. Stereoscopic pair of a motion pattern chronocyclegraph made through the use of a "fan" interruption.

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Chronocyclegraphy with a Pinhole Polaroid Camera

Stereoscopic views showing plan and elevation simultaneously aid in motion studies.

PHOTOGRAMMETRY IS BECOMING increasingly catholic in the range of disciplines in which it is now being used. Rosien (1) in an article in *Industrial Photography* discussed several industrial applications and listed other fields, but he did not touch on an application in Industrial Engineering chronocyclegraphy.

The idea of tracing the pattern of the movement of a subject's limbs to record, over a full cycle, the path of a light source and hence the path of the limbs to which it is attached, has been used for upwards of fifty years. It has been used to study not only work patterns but also medical prosthesis for artificial limb manufacture. Chronocyclegraphy was named and invented by the Gilbreths (2) who developed many means of extracting the data required relating to the motion pattern. Preston (3) drew attention to the use of Polaroid film which allows the print to be interpreted immediately after the cycle has been completed and while the detail is still fresh in the minds of both the subject and the analyst. The use of mirrors and checkered grid as a background has been suggested as a means of obtaining a three dimensional record in one photograph.

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THE OBJECT OF chronocyclegraphy is to record the passage of a light source which instantly burns through the photo sensitive emulsion, so as to record the pattern of movement, at the same time obtaining a record of the background. This latter is an essential datum point in relating the pattern which is mobile to the static environment, be it the work place, terra firma, or machinery.

By using a fast film (200–3,000 ASA) sensitive enough to be destroyed by the light source, but tolerant of the background if the background is illuminated by less than 5 foot-candles, motion cycles of up to several minutes can be recorded. However, for practical purposes, anything over 0.5 minute is difficult to interpret. The photographic procedure (which is not altogether apparent to the uninitiate) is that the cycle time does not necessarily dictate the total exposure. For practical convenience, the total exposure (which may be required to provide an adequate definition of background) can be added to the work cycle by a double exposure after the work cycle has been completed. This, in turn, implies that if very fast high contrast film is to be used, only a very small aperture is needed, or is appropriate.

It was both the limitation of funds and the fundamentally pure and simple nature of a pinhole camera that attracted the author to attempt to convert a Polaroid Land Camera 80B into a stereoscopic pinhole camera. This was accomplished as shown in Figure 1. Although admittedly the focus is not perfect, as can be seen from the Frontispiece, the advantages of the pinhole far outweigh this minor imperfection.

The advantages a pinhole offers are:

Freedom from depth-of-focus problems at close range.
The absence of parallax in view finding.
Extreme cheapness.
The ability to use films for which a commercially available equivalent lens and aperture are not readily available.
The opportunity to obtain a very precise measurement of the distance between lenses and hence the opportunity to experiment with this with the stereoscopic pair.
A very wide angle for close-up work—90°.

The pinhole lens used was drilled in an aluminium sheet which had been recessed 0.006 inch to give the same depth as diameter. This, in theory, gave a 90° angle to the lens and was found in practice to give an adequate range of admissible cycle, and total exposure duration. Because .0006 inch is considerably more than the wave length of light, all manner of theoretical optical defects exist; such as circles of confusion, which might be expected, but have not been shown to be any great deterrent in practice. Table I shows the calibration the ASA 3,000 film for a .0006-inch aperture under various light conditions.

ABSTRACT: *Motion study, as applied in industrial manufacture and in the design of artificial limbs, can be aided through the use of special stereoscopic photographs. Blinking lights attached to the moving subject create meaningful blips on photographs made with the shutter left open, where the pinhole prevents over exposure. Rectangular grids, added by double exposure, furnish a reference framework for the stereoscopic impression. An inclined mirror in the field of view shows a plan view in addition to the normal elevation view. The blips can be created either by interrupting the current to the lights or by placing a fan in front of the camera.*

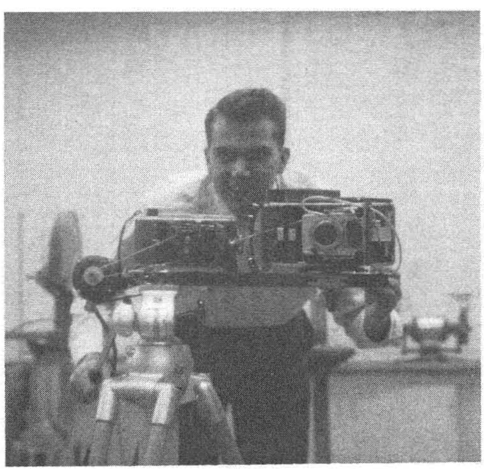

FIG. 1. Mr. D. G. Russell with a triple camera unit which he made in 1965. Mr. Russell is a student in the Department of Agricultural Engineering who undertook the technical work during the summer vacation.

TABLE 1

TABLE FOR CORRECT EXPOSURE FOR CHRONOCYCLEGRAPH

	Time					
Light Value	*Lower Limit*		*Correct Exposure*		*Upper Limit*	
Foot Candles	*Seconds*	*Minutes*	*Seconds*	*Minutes*	*Seconds*	*Minutes*
1.6	40	0.66	80	1.33	120	2.00
2	36	0.60	72	1.20	108	1.76
2.5	28	0.46	56	0.92	84	1.38
3.2	20	0.33	40	0.66	60	0.99
4	18	0.30	36	0.60	54	0.90
5	14	0.23	28	0.46	42	0.69
6.5	10	0.16	20	0.32	30	0.48
8	9	0.15	18	0.30	27	0.45
10	7	0.12	14	0.24	21	0.36
13	5	0.08	10	0.16	15	0.24
16	4	0.06	8	0.12	12	0.18
20	3	0.05	6	0.10	9	0.15
25	2.5	0.04	5	0.08	7.5	0.12
32	2	0.03	4	0.06	6	0.09
40	1.5	0.02	3	0.04	4.5	0.06
50	1	0.01	2	0.02	3	0.03
75	.5	0.005	1.0	0.01	1.5	0.015
100	.3	0.003	.6	0.006	0.9	0.009

For film ASA 3000. Camera: Polaroid 80B, pinhole 0.005 inch in 0.005 inch thick aluminum, pinhole 3.75 inch from film.

ALTHOUGH A CYCLEGRAPHY of an *un*interrupted light source is the most realistic replica of the direction of the motion pattern, chronocyclegraphy of an *interrupted* source offers interpretation of both time and direction.

Two alternative methods can be used for interrupting a light source:

By interrupting the current feeding the light, either by a tuning fork, or by a transistor circuit.

By rotating a circular fan composed of opaque and translucent blades in front of the camera lens. This has been perfected in a design by the Royal College of Aeronautics at Cranfield, U.K.

The disadvantage of interrupting the current to the bulb is that complex circuitry is needed and difficulty is encountered in calibrating the frequency of interruptions. The characteristics of practical circuits are a 6-volt current, being passed through a 1.5-volt lamp at a frequency of between 10 and 25 cycles per second with a square wave form. Transistorized devices for producing this effect are available for less than $100., which is relatively cheap. The apparatus should include provision to count the number of interruptions which would actually be found on the photograph. Although relays and counting devices will give approximately the required result, the synchronizing of the terminal "blips" with the camera shutter presents a problem.

Examination of Figure 2 shows that as the lamp element cools, it produces a comet-like tail, which permits interpretation of the direction of the motion and is also an indicator of speed.

The advantages of rotating a fan in front of the lens with a simple lamp and battery circuit are that: the subject does not become attached to a festoon of wiring; and the number of light interruptions can be synchronized with the lens opening, and closing and can be counted accurately.

The effect of the comet tail can be provided by introducing a semi-opaque blade into the fan.

One of the limitations of burning the emulsion with one brief blip of light is that the possibility exists of two blips being superimposed, and thus confused. This can occur in three ways:

1. By a motion pattern crossing so that two blips and the lens form a straight line; in practice this is very rare.
2. By the motion pattern moving in a straight line directly towards the lens.

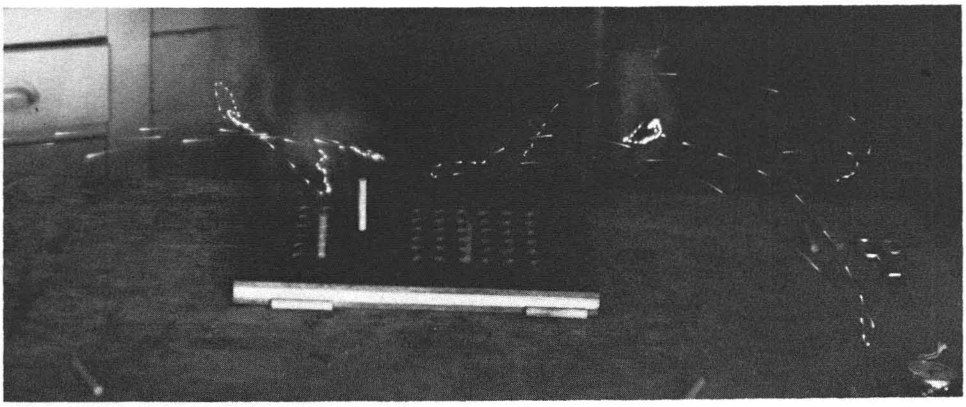

FIG. 2. A section of a motion pattern chronocyclegraph made through the use of "current" interruption. Note the comet tails.

3. The momentary cessation of movement in a motion pattern.

These confusions can be avoided by: using two cameras, or a stereoscopic camera, which remedies (1) and (2) above; and panning the camera, which remedies (2) and (3) but does not allow interpretation in relation to any static datum point. A combination of one camera being panned and a stereoscopic camera is therefore necessary if provision is to be made for a full interpretation. Such a combination has been developed using a Polaroid Land Camera, Model 120, and the modified 80B with two pinhole lenses, which are 1.5 inches apart. The combination is shown in Figure 1.

IF IT IS POSSIBLE to introduce a mirror and a grid into the background, no problem exists in interpreting each light blip in terms of an X-, Y-, or Z-coordinate. Figure 2 does not have this, but the Frontispiece does include a mirror. Interpretation is, however, greatly facilitated if at least the illusion of three dimensions and stereoscopic viewing can be provided from a pair of photographs as well as from a mirror. Because the distance of the camera from the grid background, and the angle and position of the mirror would be known, as well as the distance between the two lenses, there is no great problem of defining the true position of any point in a motion pattern if the grid is suitable calibrated.

However, it is not always possible to arrange for the background of the graph model to be viewed axonometrically, or in plan view, as in the Frontispiece. The second choice is therefore to interpose a translucent grid between the camera and the subject. If this fails, the stereoscopic pair can be interpreted in terms of contours by the normal trigonometrical means; but as a possibility usually occurs of exposing the background separately after the lights have been photographed, a grid can be superimposed (as a ghost image by double exposure) quite close to the area of the motion pattern. In fact, it can even be across the path of movement. Figure 3 illustrates the paths of light used to produce a pair such as the Frontispiece. The exaggeration of the diagram emphasizes the potential distortion and the extent of misinterpreting the apparent position of objects with their true positions.

In the diagram (Figure 3), "blip" I is intended to have a reference:

$$x = 4, \quad y = 8, \quad z = 5.$$

But in the prints its apparent position read off the grids will be:

$$\text{Right } x = 4, \quad y = 5, \quad z = 7, \quad y(M) = 3$$
$$\text{Left } x = 5, \quad y = 7, \quad z = 6, \quad y(M) = 4$$

(The inconsistency in the double quotation of y is attributable to the second position being derived from the mirror).

The diagram has been deliberately distorted because in practice, as shown in the Frontispiece, there is less than .25 inch real difference between some of the locations apparent on the prints.

The geometry and dimensions of the light paths are:

If $I\text{-}P_h = 100$ (36 inches) and I-Grid = 20

and $I\text{-}II = 50$ with $I\text{-}M\text{-}P_h = 140$.

The maximum disparity between the real position and the apparent position will depend on the relationship of the $I:II$. At a frequency of 20 cycles/second, with normal speed of "legerdemain", this in practice is

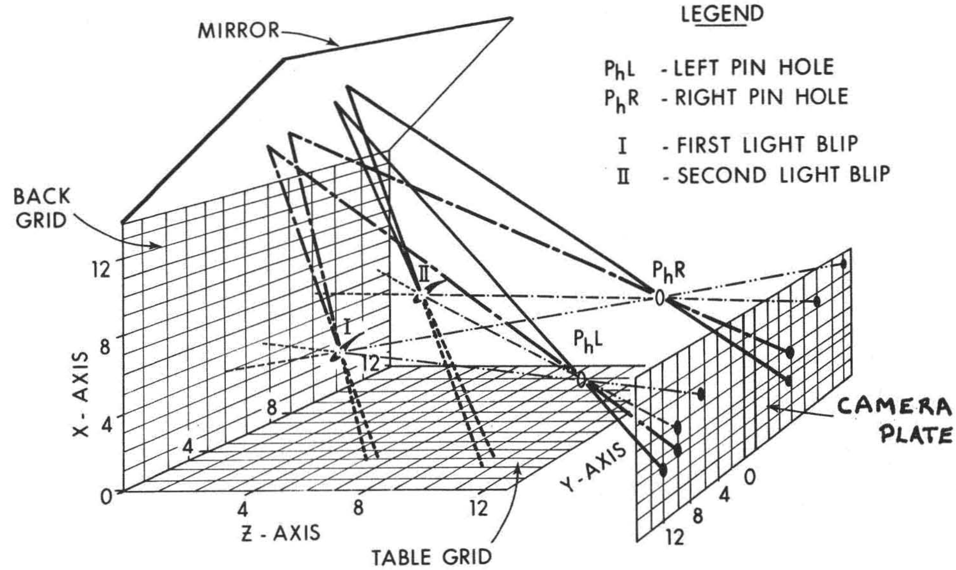

FIG. 3. Apparent actual positions of objects viewed stereoscopically. Paths of light are shown to compare the adjacent chronocyclegraph "blips" (I and II) which produce four images in the stereoscopic camera if a mirror is introduced into the field of view so as to produce both profile and plan views. The four images are 1-left, 1-right, 1-left mirror, and 1-right mirror. The broken lines show the apparent positions of the objects if the grid is not superimposed from the planes occupied by the objects. The diagram is exaggerated as the distances do not lend themselves to a scale drawing. The actual normal print size is as shown in the Frontispiece. The grid is normally marked off in 2-inch squares, with the camera never closer than 3 feet from the subject who is within ±6 inches of the grid.

rarely more than 2 inches, whereas a total motion pattern may occupy several cubic feet.

Figure 4 shows how the number 0.25 inch is derived where the distance between LP_h and RP_h is 1.5 inches, the lenses are 36 inches from the subject, and the grid is within 6 inches of the subject. This error is decreased by a factor of 2 with every multiple of 3 feet further that the camera is removed from the subject.

This same style of reasoning may be applied to the errors of the apparent position of blip *II* in Figure 3 compared with its real position. To help understand the argument, it must be assumed that blip *I* is in the only position where its apparent position is identical to its real position. This is directly in front of the camera with the mirror at 45° to the path of light from the camera and the base grid. The apparent position will be as much as 3 inches away from its true position when *I–II* becomes a maximum of, say, 18 inches.

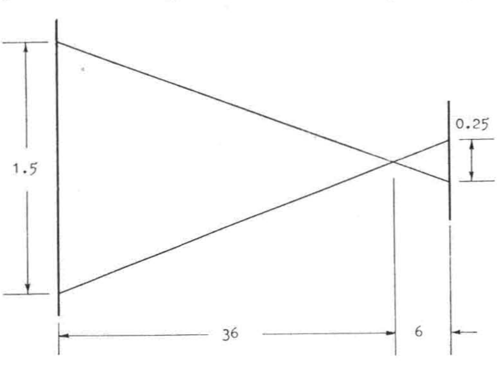

FIG. 4. The derivation of the dimension 0.25.

If the motion pattern were confined to two dimensions only, it would be possible to make a grid which would accommodate a direct reading of the grid location. For example, a two-dimensional pattern is being used in the proposed psycho motor test, which it is hoped will become an indicator of fatigue. A two-dimensional pattern is indeed a rarity. A nonlinear compensating grid can, in this case, provide for the anticipated misreadings; it would be constructed according to the curvature of the known pattern. This expedient is useful where a repetitive motion cycle is being performed under laboratory circumstances, but it is not suitable for field work. The interpretation of apparent plots is considered to be an ideal task for a digital computer, and a program could be written which would accept the apparent X-, Y-, and Z-coordinates and will convert these to the real coordinates, and at the same time calculate the actual distance moved between the various blips. By making provision also for the cumulative totals of several blips to be calculated at the same time, a presentable replica of the motion pattern can be acquired quite simply in numerical form from a single stereoscopic pair of photographs. This could be interpreted by dictation transcribed directly onto punched cards.

Procedure

The procedure for producing a stereoscopic pair with a pan-mate will depend on the nature of the interpretation required. In general principle, procedure is as follows:

1. Attach the lamps to the moving limb in such a way as to ensure they are visible throughout the cycle.
2. Estimate the duration of the cycle to be studied.
3. Decide whether there is any danger of superimposition of blips. Unless absolutely necessary, the panning camera can be eliminated by dividing the cycle into subdivisions to be analyzed separately.
4. Align the camera and measure the distance from the lens to the grid background, or other known datum points in the background.
5. Align the mirror and record its position and angle.
6. Start the counting device for light interruption.
7. Simultaneously expose lamps at a point in the cycle which is to be recorded and commence a stop-watch reading to record the length of exposure.
8. Move the subject but not the background, and fill in the background according to light intensity, aperture size and film speed to provide adequate contrast.
9. Develop the print.
10. Reconcile the first stop-watch reading with the calculated number of blips intended to be in the print with the actual number of blips on the print.

Conclusion

The normal Work Study and Industrial Engineering applications of chronocyclegraphy are intended to improve upon some existing work methods. For this purpose, the technique is usually employed empirically. It can also be used as a heuristic means of educating both foremen and workers in improved methods involving manual dexterity. This is in no sense to be regarded as a derogatory criticism of its use, for the technique and kindred ones are basically responsible for much of the improved standards of living obtained from increased manufacturing productivity.

More precise measurements are needed, however, in the basic study of agricultural ergonomics and in the fields of psychology where Polaroid stereoscopic chronocyclegraphs (*P.S.C.*) become a useful and new psycho-motor test. *P.S.C.* have the advantage of being self-recording and adapted to tasks such as the marble game and the peg-board as in Figure 3.

The technique can also be used in non-industrial physical endeavours such as Physical Education. Interest has been expressed by members of the Canadian Fitness Institute in this technique in conjunction with a force platform, a form of three-dimensional weighing scale, to evaluate athletes' performance. The characteristics of sprint start, and diving would appear to be areas to which the technique can be adapted.

The simple nature of the apparatus and the fundamental methodology, might even lead to the technique being used as a method of instruction in the early stages of teaching photogrammetry.

References

(1) Rosien, Arthur H., "New Uses for Photogrammetry," *Industrial Photography,* February, 1966, Volume 15, No. 2, page 28.
(2) Gilbreth, F. B., and L. M., "Applied Motion Study," MacMillan, 1919.
(3) Preston, T. A., "New Techniques for Chronocyclegraphs," *Work Study and Management,* July, 1965, Volume 9, No. 7, page 310.