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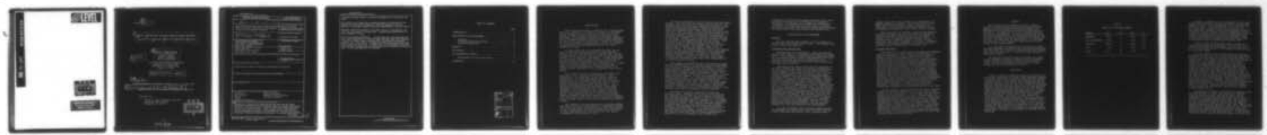

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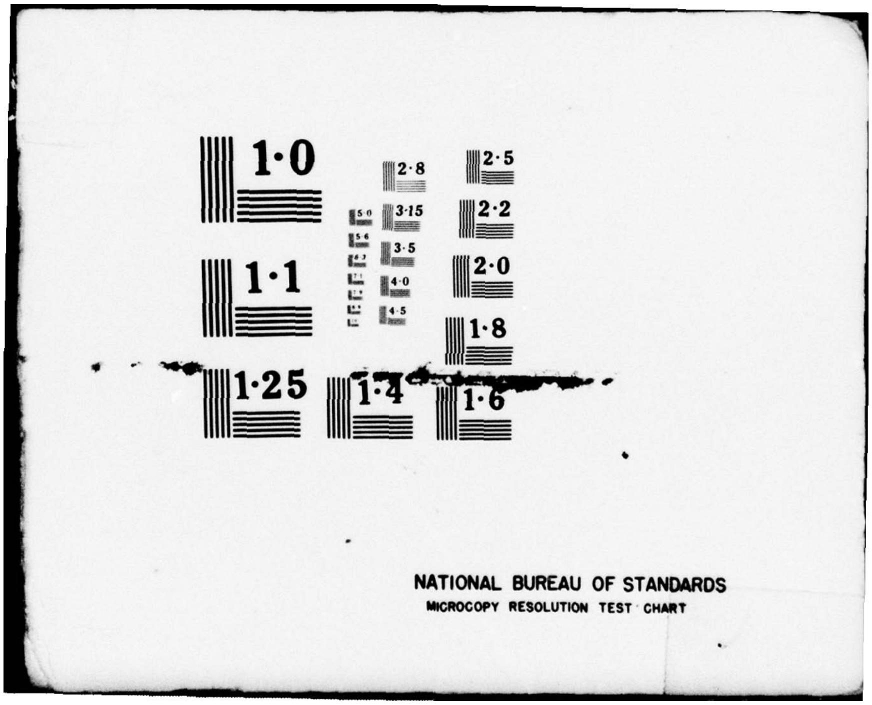
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⑭ Report 1978-3

⑥
SPATIAL ORIENTATION FROM MOTION-PRODUCED BLUR PATTERNS:
Detection of Curvature Change with Reference Gratings

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⑫ 32p.

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When driving, flying and even when walking one often can see motion-produced blur patterns that are caused by images of textures slipping over the retina and leaving trails of residual afterimages behind them which contain their motion histories. Other studies in this series on blur pattern parameters have shown that human observers can sensitively detect directional information within a blur pattern, for example when there is

(continued)

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curvature, curvature change, or relative divergence of the individual blur lines.

The purpose of this study was to determine whether the detection of blur pattern curvature change, studied in a previous experiment, would be enhanced if stationary reference lines were superimposed on the blur pattern.

Reference lines were oriented in three ways, parallel, perpendicular, and at 45° to the direction of element flow. Patterns were viewed foveally or with peripheral vision.

With the 16-element oscilloscope patterns that were used here there was only a small enhancement of curvature change detection under some conditions. It was felt, however, based on observations of naturally-occurring blur patterns, that if the density of elements had been greater, considerably more effect might have been found. It appears that a motion display of the type used here does not profit from the particular type of reference grid that was used. Further experimentation is indicated.

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INTRODUCTION

High velocities between an observer and a viewed target such as an aircraft or an array of textures on the ground create "smeared" visual perceptions in the form of blur patterns. These patterns are rich in information about the nature of the relative observer-target motion parameters. Thus it becomes important to know how well human observers are able to process this information, whether for the pilot of an aircraft using a piloted display or for the designer who must simulate three-dimensional motion on a two-dimensional screen.

If human sensitivity or processing accuracy are too poor to make use of some particular variable then the designer can save time and money by ignoring that variable in his display and the trainer of pilots can pass over that variable in his training. Conversely, if human sensitivity to a particular motion-related variable is quite high the display designer may highlight it in some way and the training procedure might emphasize attention to it. In some cases it might be possible to actually enhance human sensitivity through techniques of display design or of cockpit design, especially in the transparent areas of the canopy.

In a previous series of experiments (Harrington and Harrington, 1977; Harrington and Harrington, 1978) sensitivity to an assortment of blur pattern variables was measured. In those experiments care was taken to prohibit the use of external references such as the side of the display by using a round viewing area. In the present experiment the opposite tack was taken. One of the previous experiments was replicated in part using references along with the pattern to see if detection thresholds could be lowered to any significant extent. Specifically the observers viewed a subset of the same stimuli that observers serving in the curvature change detection threshold experiment (Harrington and Harrington, 1978) had viewed. This time, however, there was a reference set of straight lines in front of and touching the viewing surface.

The purpose of the experiment was to determine whether the lines could aid in the detection of sinusoidal oscillation of the 16-element blur pattern when they were oriented in one of three ways, parallel to the pattern's direction of flow, perpendicular to the direction of flow and at 45 degrees to the direction of flow.

The three orientations of the reference grid were chosen because it was felt that the parallel and perhaps even the perpendicular references would represent very special cases since the human visual system is extremely accurate when judging parallelness (Harrington, 1967) and also quite good with perpendicularity. The particular motivation here was that if in a piloting situation some particular form of motion was desired it might be possible to superimpose a reference pattern peculiar to that form of motion over the blur pattern, whether it be a naturally occurring pattern on the ground or a simulated pattern on the screen. Then the observer could hopefully match the blur pattern resulting from his controlling actions to the reference patterns on the screen. For example, when a pilot is being taught to land he must learn to flare out at a specific angle. It would be possible to put a few reference lines on a judiciously chosen section of the canopy that matched that desired angle. Similarly in conditions of lowered visibility it might be possible to configure a reference source to match blur lines from runway lights or artificial textures on the runway that corresponded to the desired angle of motion.

With regard to perpendicularity, blur patterns appear that are perpendicular to a reference often when one looks to the fore of a moving vehicle; for example, if the hood of an automobile is square to the line of motion, perpendicular blur patterns can be seen that lose perpendicularity quite noticeably when the automobile turns. The same situation exists for the pilot of an aircraft or other moving platform; however, in this case perpendicularity relates also to drift. In a cross-wind landing, drift can be detected when the blur lines change their angles relative to parts of the craft. Then, if the pilot adopts a crabbed attitude, a new blur line angle is established and he can maintain his attitude by keeping this angle constant. Therefore it is of considerable interest to know how well this kind of information can be processed.

The parallel reference possesses an additional potential asset. When blur lines are not quite parallel to a reference edge either they will emerge from behind the edge part way down its length or they will disappear part way down depending upon the orientation. If a number of parallel reference edges are available, the possibility of flickering occurs. This could be extremely important in applications to low level orientation and guidance because of the peripheral retina's exquisite sensitivity to certain types of flicker. In the experiment to be reported here, eight parallel wires were stretched across the viewing screen and oriented either perpendicularly, parallel to or at 45 degrees to the straight-line trajectories of the moving elements and then side-to-side sinusoidal oscillation of the elements was gradually introduced. The purpose was to compare the performance of observers in these conditions with that of observers performing in the previous curvature change experiment where the same patterns were used without the reference grid.

DESCRIPTION OF THE EXPERIMENT

Subjects

All ten subjects were students at the University of Nevada, Reno, with normal visual acuity. All subjects were paid for their participation.

Procedures and Instructions

Subjects were run individually. During the session subjects were seated in a darkened viewing booth 29 inches from a 5-inch diameter circular scope and familiarized with the two fixation points (central and peripheral--30° left) that they would use during the experimental trials. Subjects' eyes were monitored to ensure their maintaining the appropriate fixation.

Each subject was familiarized with the parameters of the visual display and given the following instructions: "At the start of every trial you will see a pattern of moving elements on the screen in front of you. Say 'no', if the elements appear to be moving along a path with constant curvature; say 'yes', if the elements appear to be moving along a path with changing curvature. During each trial, a pattern of elements moving along a constant path may gradually begin to move along a changing path. As soon as you notice *any* amount of change, respond with 'yes'. A pattern of elements moving along a changing path may begin to move along a constant path. As soon as you fail to see contractions, say 'no'. Sometimes the pattern of elements will remain the same during the entire trial. Therefore, you must be somewhat certain that you notice a change before you respond. The straight lines that are on the front of the screen will be orientated in one of three ways to the blur lines; parallel, 45°, and perpendicular. You are to utilize these lines as reference points when making your judgments." Figures 2, 3 and 4 show stages of the stimulus pattern that the subjects actually saw with the reference grid superimposed.

In order to ensure that the subject understood the instructions, each subject was given ten training trials; a trial began when the subject, after fixation, made a judgment about the visual display and it ended when the subject changed his judgment. The starting point on the wheel outside the booth was randomly selected by the experimenter, and the subject determined whether it was an ascending or descending trial by his initial response.

This experiment was designed to measure the subject's threshold for detecting curvature change (threshold was defined as the mean "stopping point" or end response averaged over the ascending and descending trials). The angular velocity remained constant at 8°/sec and the horizontal oscillation frequency at one hertz. During the experiment each subject responded to twenty trials (ten ascending and ten descending) in each condition.

Stimulus Generation

The stimuli were electronically generated and presented on an oscilloscope. Figure 5 shows the arrangement. In common synchronization with a digital clock a vertical sawtooth provided the downward motion of the trace, a 16-step generator provided the horizontal levels necessary for each of the 16 vertical sweeps to be positioned and a 32-step square pulse generator stepped through a memory that was loaded to provide one "on" location per vertical line, thus giving one element on each vertical line when the trace modulation was turned on. Divergence of the vertical lines employed in other experiments was induced by mixing some of the vertical signal with the horizontal signal so that as the trace moved downward its horizontal component increased to spread out the lines at the bottom. Curvature of the patterns, employed in a previous experiment, was produced by introducing a controlled amount of signal from a memory that had been programmed to give the appropriated magnitudes of offset, into the horizontal deflection. Curvature change was brought about by sinusoidally attenuating the horizontal signal to the scope.

In the curvature change experiment the rate of pattern advance was variable, assuming one of three values under control of the experimenter. In this experiment the angular velocity was held constant at 8°/sec. The frequency of sinusoidal attenuation was also held constant. Subjectively the impression was of side-to-side motion imposed upon the downward flow of the elements as though one were looking at individual elongated bars on the ground below a helicopter flying a sinusoidal but level pattern. The element trajectories in Figure 5 are appropriate to designate the paths of the individual elements but in real time all of the elements would be seen flowing en masse back and forth left to right as they proceeded downward and all would have the same slopes at the same time.

RESULTS

The results of the experiment appear in Figure 1. Oscillation thresholds in tenths of an inch are plotted against the three orientation conditions wherein the reference grid lines were positioned such that they were parallel or perpendicular to or at a 45 degree angle to the element trajectories. The curve bearing small letter 'p's was obtained from data collected when the subject was fixating 30 degrees left of the center of the oscilloscope display. The curve with the small letter 'c's indicates the condition in which subjects fixated directly on the center of the display screen.

For comparison the dotted lines indicate data from a previous experiment in which stimuli and viewing conditions were identical but in which no reference lines were present. These are labeled 'p' and 'c' again to denote peripheral and central viewing.

An analysis of variance shows that there is a significant difference between the central and the peripheral viewing conditions and also between the grid orientations. The grid orientation versus fixation location interaction was not significant (Table 1).

DISCUSSION

Figure 1 shows the comparison between the results of the current experiment and those of the experiment reported previously dealing with curvature change threshold without a reference grid. Even though the peripheral and central fixation conditions did lead to lower thresholds when the parallel reference grid was used as was initially predicted, the most striking fact about these data is that thresholds obtained with the reference grid are on the same general order of magnitude as those obtained without it. Several things both phenomenological and emperical had indicated that thresholds would drop dramatically with reference lines in the field. First of all, when viewing the sinusoidal lateral oscillations with the grid in place, it is possible to detect departures of the element trajectories from being parallel to the wires of close to 0.01 inch, especially if a particular element is very close to or even partially covered by a reference wire. Then the element may even appear and disappear as it travels down the screen. Therefore it had seemed that observers would easily detect horizontal oscillations of the same order of magnitude.

Table 1

ANALYSIS OF VARIANCE SUMMARY

SOURCE	SS	dF	MS	P
Subjects	76.00	7	10.85	<.01
Ref. Orientation	12.78	2	6.39	<.01
Fixation	38.88	1	38.88	<.01
BxC	1.94	2	0.97	N.S.
Error	21.1	35	0.60	

Secondly, a number of visual capacities that one might suspect were related to the task can operate on much more sensitive levels. For example Brown (1961) has shown that humans are able to detect velocities on the order of 0.1 cm/sec when a reference that is stationary is close by. Even though the targets in the current experiment do have a moderate vertical velocity, this is considerably below the range of our maximum lateral velocities produced by the sinusoidal oscillations. Also acuity and dynamic visual acuity capabilities of the human visual system are known to exceed this level of sensitivity (Sulzer, 1954).

It may be that subjects simply did not notice the appropriate aspects of the display. They were not at any great length instructed to use these cues nor were they strongly made aware of them. More specific training really may have been needed.

A second variety of blur pattern slope or curvature detection aid comes not from the craft but from the surface producing the blur pattern. In many situations there are actual lines on the viewed object that can provide reference information. For example an airport's or an aircraft carrier's landing surfaces have lines on them from structural configurations such as welds, painted guide lines, scuff marks from previous landings and so forth. Highways usually have dividing lines and other reference lines and edges that are customarily parallel to the direction of motion. When the blur lines are parallel to the real lines and edges on the viewed surface it can tell the observer that his motion also is parallel, and when the blur lines are no longer parallel then he knows that he is moving with relative obliqueness. Figure 6 shows this situation graphically. A picture was taken with slow shutter speed from a car moving on a path that was the surface shown in the photo. Note how little blurring is present in the painted line and note the angle that the pattern of blurs makes with it.

One potentially powerful orientation aid emerging from the consideration of actual lines serving as reference lines for the blur pattern information comes from an extension of the principle that is evident in Figure 6. In addition to having straight reference lines it would be wise to include spots beside them to offer the observer an index of his own motion to compare with the index of ground orientation provided by the runway line. Then if the observer were travelling parallel to the line at a velocity sufficient for producing good blur patterns, and if he looked at the line and the spots beside it, he would see blur lines parallel to the reference line. If the aircraft started to drift laterally then the observer would see the pattern appearing in Figure 7, where blur lines from the spots approach the static line at a particular angle, directly related to the angle of drift and pointing in the direction of drift.

THE MATHEMATICAL MODEL

Following is a parameterization of the visual plane, the plane in which the stimulus pattern appears, in terms of the ground plane variables. The purpose of this development is to allow a designer or psychophysical investigator to determine with appropriate transformations what varieties of motion and of blur patterns will be seen in the visual plane corresponding to particular motions on the ground plane. Conversely, it is often necessary to know where particular kinds of motion or of blur patterns will be found on the ground, for example when applying the data of these experiments. For instance it might be desired to know where in the surroundings of a low-flying pilot he might be able to find blur patterns of a particular curvature corresponding to his threshold for blur pattern curvature. Or in training for a new visual situation it is often necessary to analyze the visual conditions in terms of angular velocities so that the visual task can be matched to the operator's capabilities, in this case perhaps so that his response to at a display can be predicted. Essentially this involves projecting or transforming the ground onto the display plane or visual plane. One starts by putting the observer at the point $(0,0,h)(h>0)$. The path of the aircraft, initially is $[x,y,z-h] = t[0,1,0]$ (1)

$$\frac{x}{0} = \frac{y}{1} = \frac{z-h}{0} \quad ,$$

i.e., level flight in the Y-Z plane. The line of sight of the observer is given by $[x,y,z-h] = t[0,A,B]$ (2) where A and B are direction cosines (see Figure 8). $A=\cos(\alpha)$, $B=\cos(\beta)$. Note that A and B are both negative and that $A^2 + B^2 = 1$.

The visual plane contains the "porthole" and is perpendicular to the line of sight at a (positive) distance d from the observer. The equation of the visual plane is:
$Ay + B(z-h) - d = 0.$ (3)
The family of all planes containing the line of flight (1) shall also be considered. This family is given by
$\chi + C(z-h) = 0$ where C is any non-zero real number. (4)

The intersection of the family of planes (4) with the visual plane gives us a family of lines:

$$\left[X + \frac{Cd}{B},\ y,\ z-(h + d/B)\right] = S\left[1, \frac{B}{AC},\ -1/C\right] \tag{5}$$

These lines have a common point of intersection (0, d/4, h)

Coordination of the Visual Plane

One wishes to establish a coordinates system on the visual plane so that various curves which are traced out may be identified. Pick for the vertical axis, $\hat{Y}$, the vector from (0,0,h+d/B) (point of intersection of the visual plane and the z-axis) to (0,d/A, h) (the point in common to the family of lines(5). This vector is [0, d/A, -d/B]; a unit vector in the same direction is [0,B,-A].

For the horizontal axis, $\hat{Y}$, use the vector [1,0,0].

Hence the transformation from E_3 to the visual plane is given by:

$$\begin{pmatrix} \text{VECTOR to become } \hat{i} \\ \text{VECTOR to become } \hat{j} \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & B & -A \end{pmatrix}$$

Origin, 0′, in the visual plane, has E_3 coordinates of (0, Yo, h +). If P(a,b,c) is a point on the visual plane, its coordinates relative to $\hat{X}, \hat{Y}$) are given by

$$\begin{pmatrix} 1 & 0 & 0 \\ 0 & B & -A \end{pmatrix} \qquad \begin{pmatrix} a - o \\ b - yo \\ c - (h+dB) \end{pmatrix} \tag{6}$$

Motion

Suppose that the observer at any time t has position given by $\overline{P}(t) = [0, Y(t), z(t)]$; i.e., motion in Y·Z plane. The direction (A,B) of the line of sight (2) will remain the same. The visual plane, however, will vary with time. If Z(0) = h and Y(0) = 0 then

$$A(y-y(t) + B(Z-Z(t)) - d = 0 \text{ will be the visual} \tag{7}$$
plane at time t.

Let $(X_1, Y_1, 0)$ be any point in X-Y plane. One wishes to find the coordinates (as a function of time) in the (moving) visual plane. To do this consider the line of flight (1) as constant, regardless of the actual flight of the vehicle. Also the direction of the line of sight will remain invariant.

There is a unique plane in the family of planes (4) which contains the point $(X_1, Y_1, 0)$. One intersects the line in that plane which contains $(X_1, Y_1, 0)$ and is perpendicular to the line of flight with the (moving) visual plane. The point of intersection (as a function of time):

$$X = X_1 \left[1 + \frac{A(Y_1 - Y(t_1) - d}{B} - \frac{z(t)}{h} \right]$$

$$Y = Y_1$$

$$Z = Z(t) + \frac{d - A(Y_1 - Y(t))}{B}$$

The $\hat{X}$-$\hat{Y}$ coordinates (as a function of t) are:

$$\hat{X}(t) = X_1 \left[1 + \frac{A(Y_1 - Y(t)) - d}{B} - \frac{Z(t)}{h} \right] \qquad (9)$$

$$\hat{Y}(t) = B(Y_1 - Y(t)) + \frac{A^2}{B} \left[(Y_1 - Y(t)) - dA \right]$$

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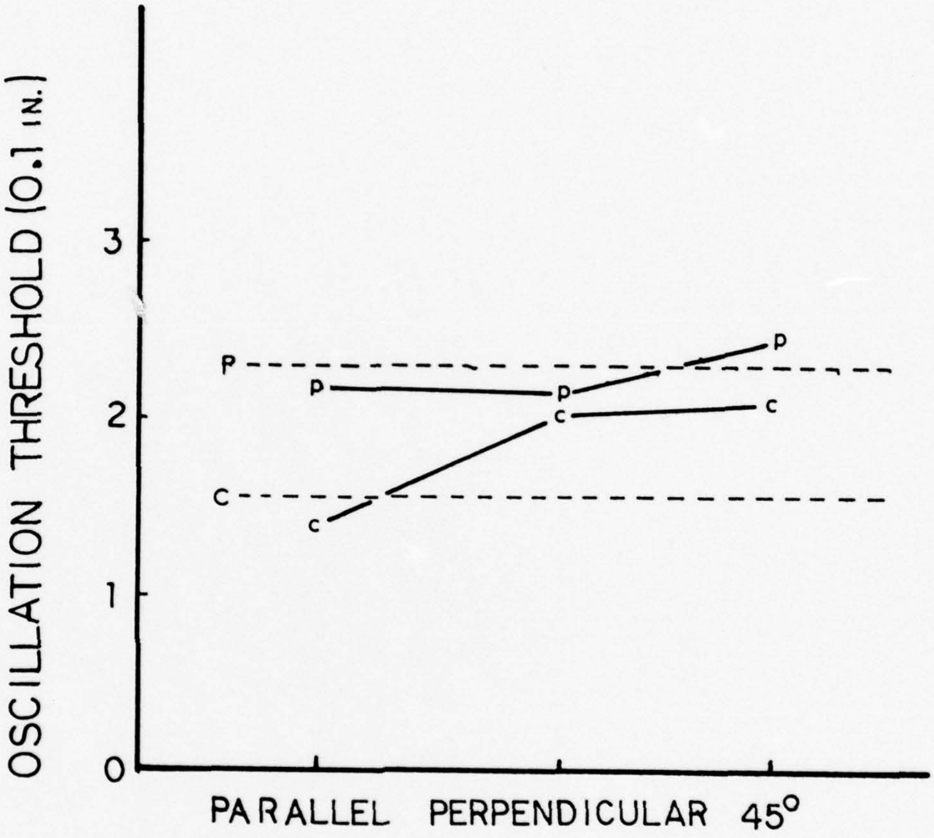
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FIGURE 1

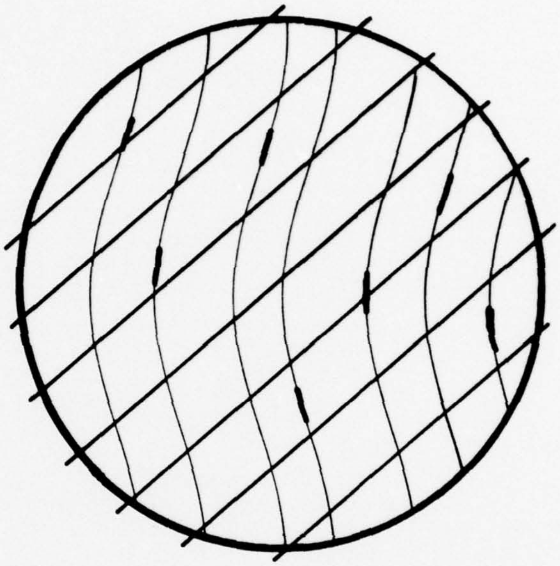

FIGURE 2

Schematic diagram showing display with reference grating at 45-degree angle.

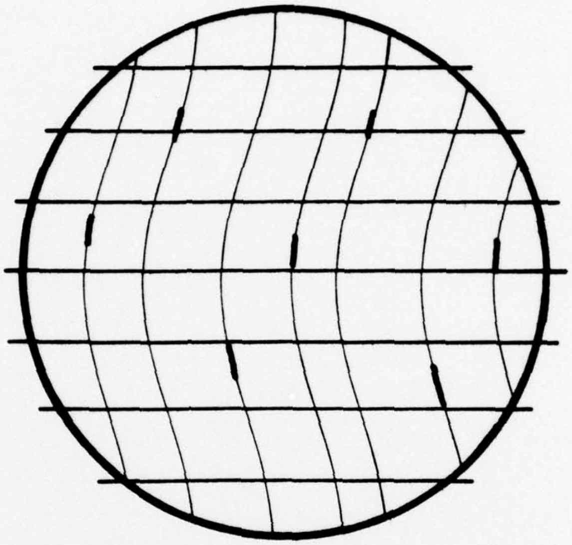

FIGURE 3

Schematic diagram showing display with horizontal reference grating.

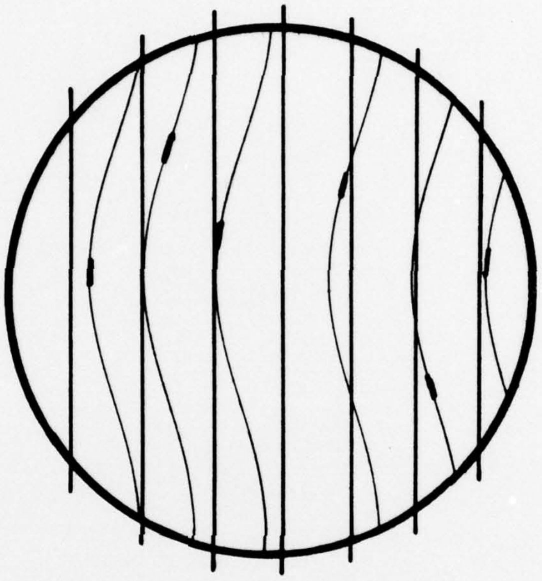

FIGURE 4

Schematic diagram showing display with vertical reference grating.

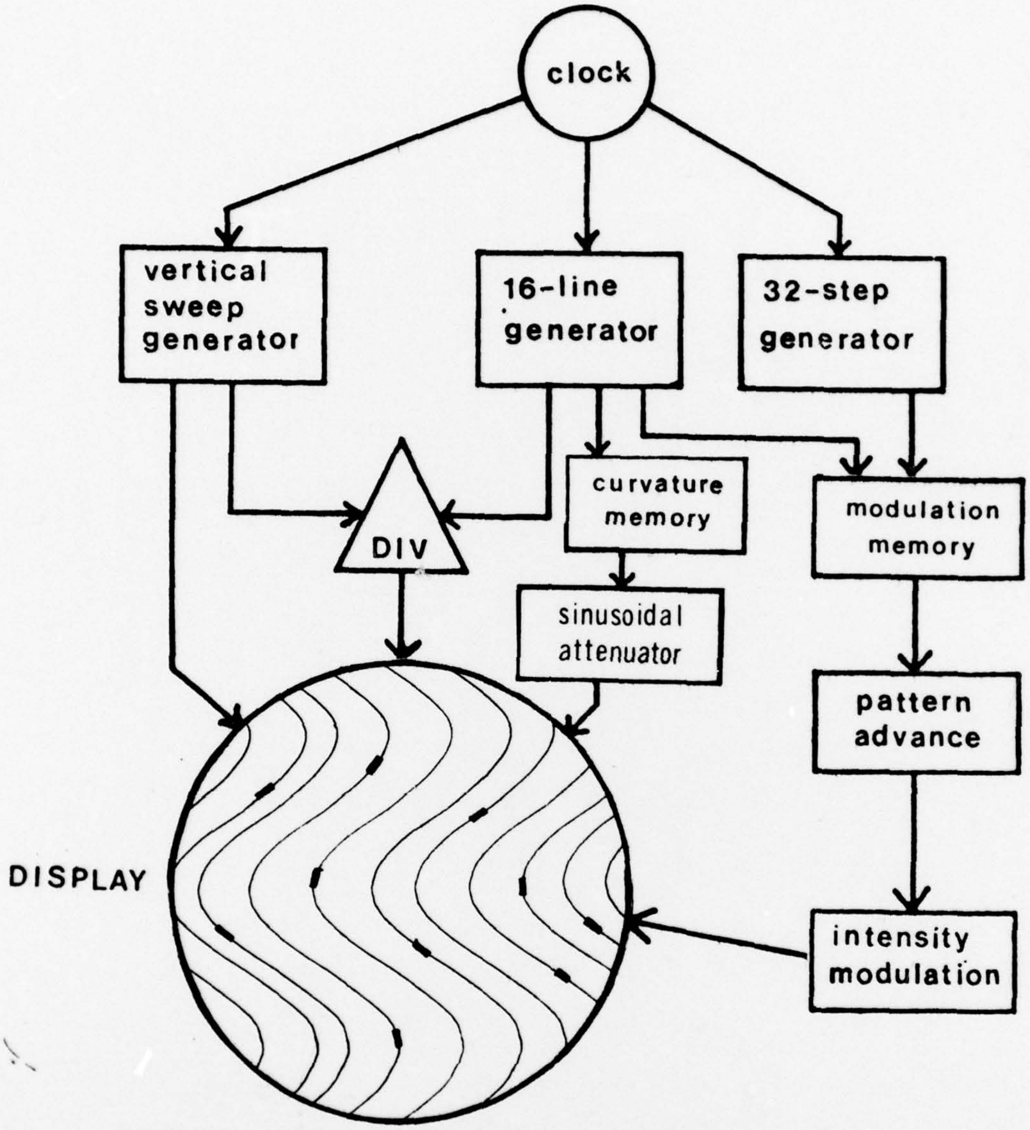

FIGURE 5

Schematic diagram of the synthetic blur pattern generator. In common synchronization with the clock, vertical lines on the display are produced by the vertical sweep generator, displaced successively from left to right by the 16-line generator and modulated to produce one element per line by the 32-step generator, the memory and the intensity modulator. Divergence is produced by mixing varying amounts of sweep signal with the horizontal displacement generator. Curvature change is produced by sinusoidally attenuating the curvature signal.

FIGURE 6

Blur lines of varying curvature photographed from a turning automobile. The small amount of image slippage that will produce a visually useable blur pattern is evidenced by the relative clarity of the white parking strips.

FIGURE 7

Reference dats painted alongside a reference bar show angle of drift.

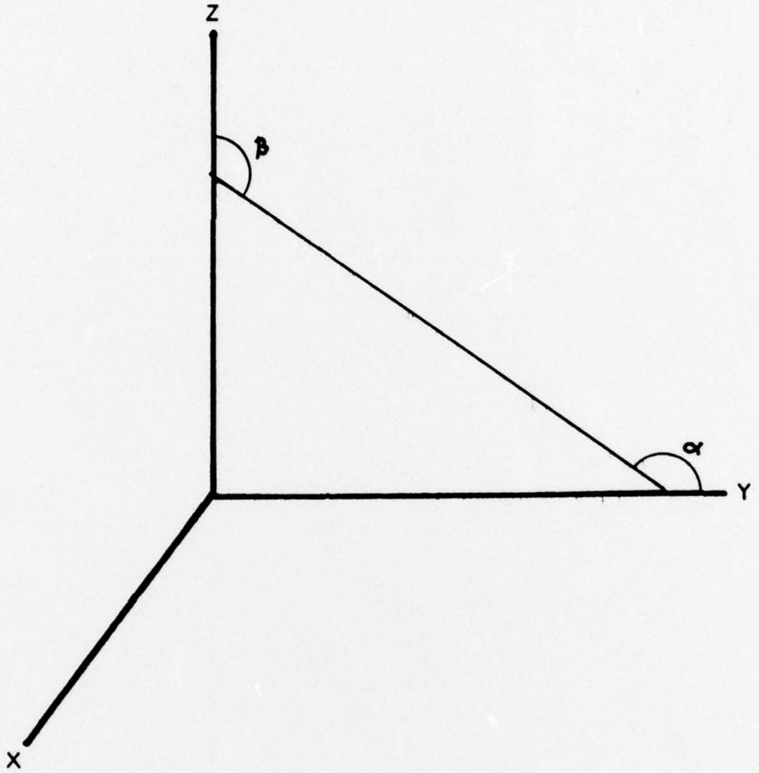

FIGURE 8

Direction cosines of the line of sight of an observer moving straight and level in the y-z plane.

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