

July 26, 1966

L. I. GOLDFISCHER

3,263,088

STAR FIELD CORRELATOR

Filed Aug. 27, 1963

4 Sheets-Sheet 1

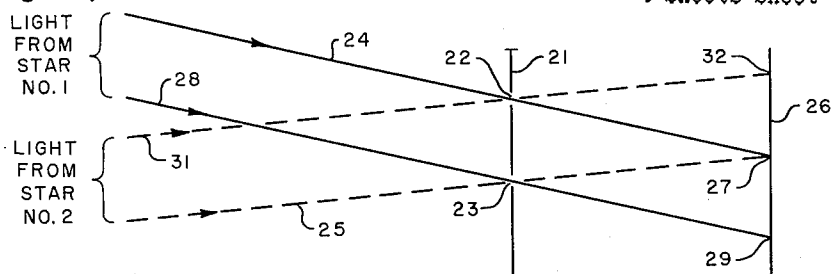


FIG. 1

FIG. 2

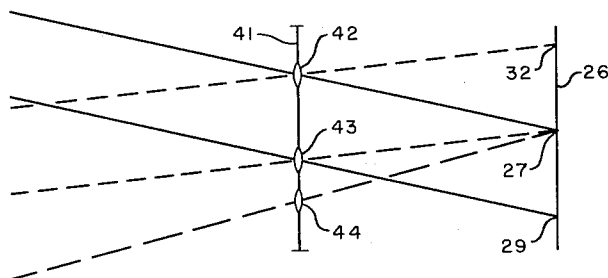


FIG. 3

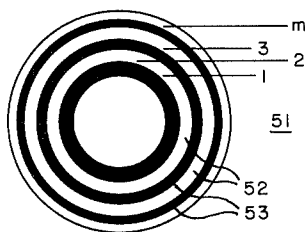
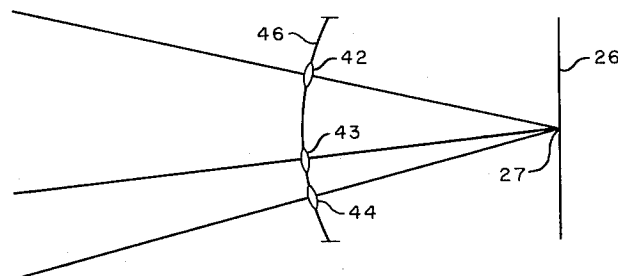


FIG. 4

INVENTOR.
LESTER I. GOLDFISCHER

BY *A. S. Macpuf*

ATTORNEY.

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L. I. GOLDFISCHER

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4 Sheets-Sheet 2

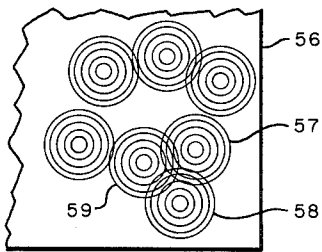


FIG. 5

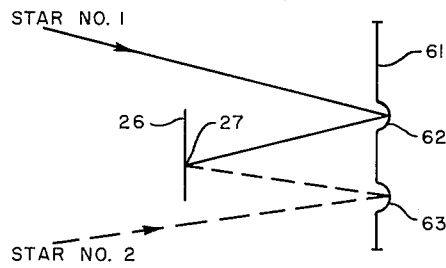


FIG. 6

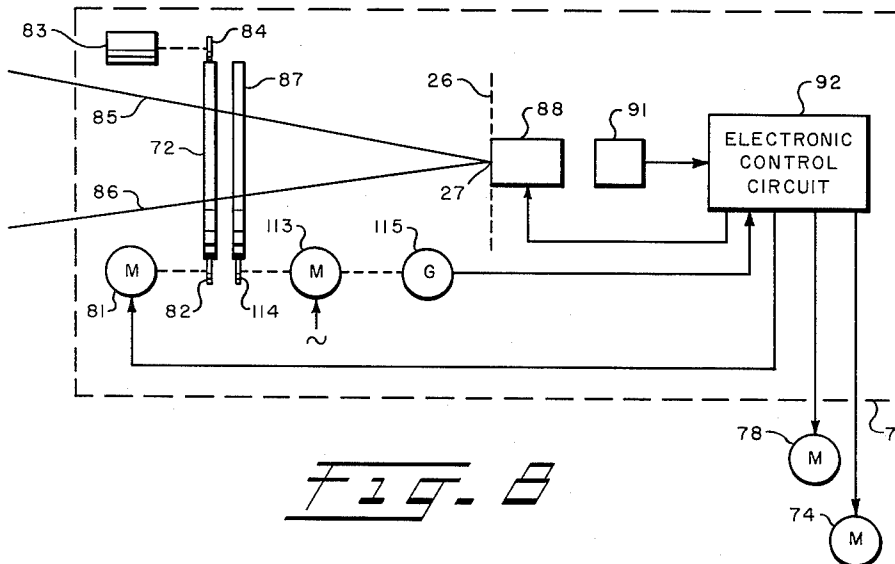


FIG. 8

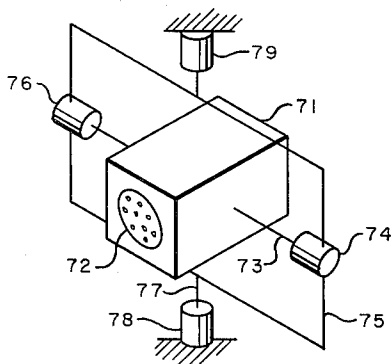


FIG. 7

INVENTOR.
LESTER I. GOLDFISCHER

BY

A. S. Machus

ATTORNEY.

July 26, 1966

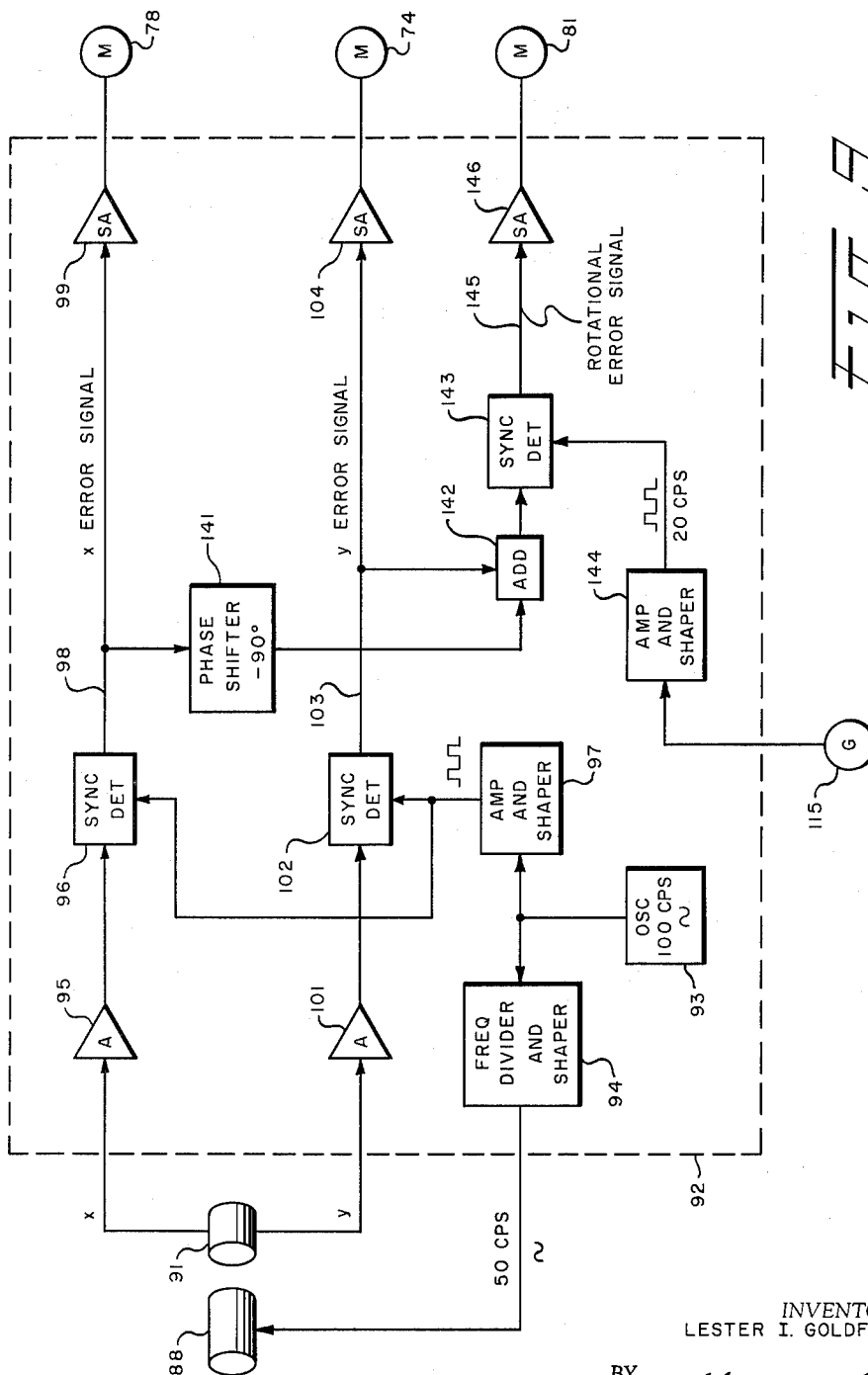
L. I. GOLDFISCHER

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INVENTOR.
LESTER I. GOLDFISCHER

BY

A. A. Machey

ATTORNEY.

July 26, 1966

L. I. GOLDFISCHER

3,263,088

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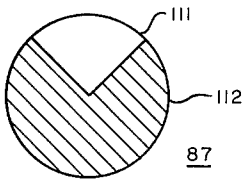


Fig. 10

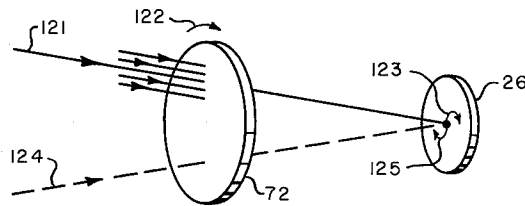


Fig. 11

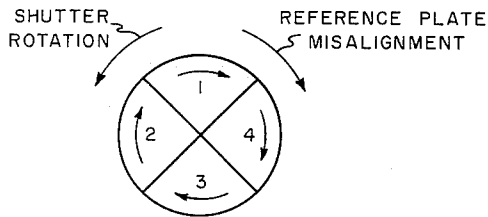


Fig. 12

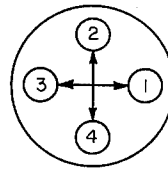


Fig. 13

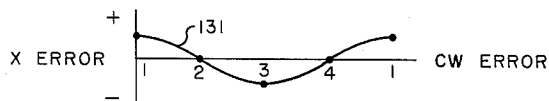


Fig. 14

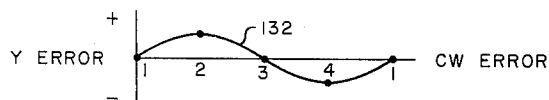


Fig. 15

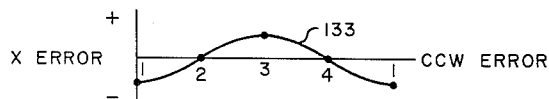


Fig. 16

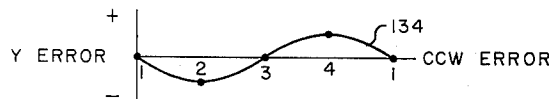


Fig. 17

INVENTOR.
LESTER I. GOLDFISCHER

BY *A. S. Macbee*

ATTORNEY.

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3,263,088

STAR FIELD CORRELATOR

Lester I. Goldfischer, New Rochelle, N.Y., assignor to General Precision, Inc., a corporation of Delaware

Filed Aug. 27, 1963, Ser. No. 305,575

11 Claims. (Cl. 250-237)

This invention relates generally to apparatus employing optical auto correlation techniques for determining the attitude of a body with respect to the celestial sphere. More particularly, the invention relates to apparatus which matches the unique pattern of a number of stars to a reference pattern by a single pointing and alignment operation, i.e., with a single optical field.

The designer of orbital and reentry vehicles, satellites, space probes, and space vehicles is faced with the problem of determining directions in space for purposes of orientation control and as an input to navigation and guidance equipment. The obvious solution is to establish two or more independent lines of sight to the celestial sphere since a single line of sight to a single star establishes direction but not orientation. This solution has the obvious disadvantage of requiring several optical systems together with their associated circuitry.

Another solution proposed in the past uses optical correlation techniques. An objective lens forms an image of the star field in a portion of the celestial sphere. A map reference of this field is positioned near the image. A second lens focuses light passing from the image through the reference onto a correlation plane where a detector senses the condition of the match between the image and the reference. This arrangement places severe requirements on the quality of the lenses and on the sensitivity of the detector because of the necessity for forming a sharp image of the star field and because of the low light intensities involved.

It is a general object of the present invention to provide apparatus for determining continuously the orientation of a body with respect to the celestial sphere.

Another object is to provide apparatus for determining the orientation of a body about three orthogonal axes using but a single optical field.

Another object is to provide an improved light transmissive map or reference of a selected region of the celestial sphere.

Another object is to provide a light transmissive map having improved light gathering power.

Another object is to provide a light transmissive reference producing improved resolution of the correlation spot.

Another object is to provide an improved auto correlator for determining translational and rotational misalignment substantially free from interference due to background illumination.

Briefly stated, the invention involves matching, by means of optical correlation techniques, of a stored reference pattern of a desired region of the celestial sphere with the field of stars actually occurring in that region. The reference pattern comprises a film or plate opaque except for discrete points representing the positions of a number of selected stars. Each point, instead of being simply a transparent portion, is provided with a focussing element such as a small lens or a Fresnel zone plate. Each lens or zone plate focuses light from its corresponding star to the same point in the detecting plane, forming a sharper and more intense correlation spot than could be formed by a simple transparent area or pinhole of any size. The spot so formed is detected and error signals are generated to position the apparatus for optimum correlation. Also included are mechanisms for minimizing or compensating for the deleterious effects of background illumination.

For a clearer understanding of the invention reference

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may be made to the following detailed description and the accompanying drawing, in which:

FIGURE 1 is a schematic diagram of a correlator using a reference plate having small apertures;

FIGURE 2 is a schematic diagram of a correlator using a planar reference plate provided with small lenses;

FIGURE 3 is a schematic diagram of a correlator in which small lenses are mounted on a section of a spherical shell;

FIGURE 4 is a schematic diagram of a Fresnel zone plate;

FIGURE 5 is a schematic diagram of a planar reference formed with several zone plates;

FIGURE 6 is a schematic diagram of a correlator using small spherical mirrors;

FIGURE 7 is a schematic diagram showing how the apparatus is mounted;

FIGURE 8 is a schematic diagram of a preferred form of correlator;

FIGURE 9 is a schematic diagram showing circuit details in addition to those shown in FIGURE 8;

FIGURES 10-13 are schematic diagrams useful in explaining the invention; and

FIGURES 14-17 are graphs useful in explaining the invention.

Auto-correlation techniques may be regarded, in general, as addressed to the problem of matching, or bringing into registration, two areas containing essentially the same pictorial content. The simplest example is that of a pair of identical transparencies in contact with each other. When such a pair is held up to a light and one of them shifted with respect to the other, it is observed that maximum light is transmitted through the pair when best registration is achieved. A converging lens may be used to focus the transmitted light to a spot on the focal plane where it can be readily observed or measured.

A similar situation exists when the two transparencies are not in contact but rather are separated by a significant distance. Here again it is observed that maximum light is transmitted along the line of best registration. It is further observed that the focal plane exhibits a bright spot, called the correlation spot, centered around the point intercepted by the line of best registration, while the remainder of the focal plane is less brightly illuminated. When one transparency is translated without rotation, the correlation spot is correspondingly translated. Rotation of one transparency causes a blurring of the correlation spot which, upon continued rotation, completely disappears into the background.

When the two areas to be matched have the same pictorial content but different scale factors, that portion of the transmitted light representing the correlation function converges to a spot even without a lens. When the scale factors are widely different, as in the case of matching a transparency of an aerial photograph with the actual scene from which it was made, the focal plane lies quite close to the small scale version of the subject. This is the so-called lensless configuration and is the configuration of principal interest for present purposes. As in the previous case, translation of one area (usually the small scale version) translates the correlation spot while rotation diffuses it.

Optical correlation techniques in general, and the lensless configuration in particular, are eminently suitable for star field matching. However, unlike ordinary pictorial sources, for which the intensity is largely a smooth and continuous function of position, star fields are a collection of sharp pulses of intensity randomly distributed in position within the field. A reference constructed to duplicate the star field of interest as closely as possible at a reduced scale comprises an opaque film or plate pierced by a number of transmitting pinholes positioned at points corre-

sponding to the locations of the brightest stars in the selected region of the celestial sphere. Such a reference is shown schematically in FIGURE 1 wherein the film or plate 21 is shown formed with but two pinholes 22 and 23 for illustrative purposes. A ray of light 24 from a first star passes through the pinhole 22 and intersects a ray of light 25 from a second star which passes through the pinhole 23. A detecting plane 26 is placed parallel to the plate 21 at the intersection 27 of the rays 24 and 25. Although a ray 28 from the first star passes through the pinhole 23 to the point 29 and a ray 31 from the second star passes through the pinhole 22 to the point 32, it is obvious that the point 27 is brightest and represents the correlation spot. With the detecting plane 26 stationary, translation of the plate 21 translates the spot 27 while rotation diffuses it.

The correlation peak obtained with the arrangement of FIGURE 1 is quite sharp but contains very little power because the light gathering power of each pinhole is quite poor. An obvious way of increasing the light gathering power is to enlarge each pinhole. This increases the power of the correlation peak but also broadens it. Additionally, the power of the background illumination, represented in FIGURE 1 as the power at points 29 and 32, is also increased. Hence the potential ability of a detector in the plane 26 to resolve the position of the correlation peak is not improved.

Referring now to FIGURE 2, there is shown a plate 41 formed with a number of enlarged apertures containing small lenses such as the lenses 42, 43 and 44, the focal plane of each of which is at the detecting plane 26. The resulting reference has improved light gathering power and the width of the correlation peak is limited only by the diffraction pattern associated with the lens apertures and by the lens aberrations. Each lens forms a diffraction limited image of its corresponding star at the same point 27 in the detecting plane 26. All of these images are superimposed and add up to the correlation peak. The images of non-corresponding stars such as those formed at the points 29 and 32 generally do not become superimposed and the sum of these cross-correlation images forms the background intensity in the detector plane. Thus, the sample correlation peak not only contains more light than when only the small pinholes are used but in addition is confined to a smaller area in the detecting plane.

It is to be noted that in the arrangement of FIGURE 2, most of the star images which are superimposed to form the correlation peak are brought to an off-axis focus. This situation can be corrected by the arrangement shown in FIGURE 3 wherein the reference comprises a plate or dish 46 fabricated as a section of a spherical shell and containing suitable apertures in which the lenses such as the lenses 42, 43 and 44 are placed. The radius of the shell 46 is equal to the focal length of the lenses and each lens is oriented so that its optic axis passes through the center of the sphere containing the reference shell 46. With this arrangement each star is imaged on-axis by its corresponding lens and only the cross-correlated images are subject to off-axis focus. This relieves considerably the strain on lens design. Off-axis defocussing of the cross-correlation images even proves an advantage by providing background smoothing, thereby making the detection of the auto-correlation peak easier.

The arrangements of FIGURES 2 and 3 have an inherent limitation. With any given number and arrangement of stars and any given size of reference plate, the lenses must be small enough to avoid overlapping. This limits the increase in light gathering power attainable by increasing lens size. This and other limitations can be overcome at least in part by the use of Fresnel zone plates instead of lenses.

FIGURE 4 shows a film or plate designated generally by the reference character 51 which comprises a plurality of transparent zones 52 alternating with opaque zones 53.

Such a plate may be made by photographic techniques. The radii of transition from transparent to opaque and vice versa, designated 1, 2, 3 . . . m in FIGURE 4, are chosen to make the difference in path lengths from the focal point of the zone plate to the two edges of any zone equal to one half the wavelength at the operating frequency. It can be shown that the radius of the m th transition, r_m , may be expressed, to a very good approximation, as

$$r_m = \sqrt{m\lambda f} \quad (1)$$

where λ is the wavelength and f is the focal distance. For example, a zone plate with a focal length of eight inches has been constructed for use with light having a wavelength of about 0.5 micron. One such plate was about one-half inch in diameter, had a central transparent area with a radius of approximately 0.0318 centimeter (radius of the first transition), and had 200 transparent and 200 opaque zones. Such zone plates have been studied in considerable detail but for present purposes it is sufficient to note that they are capable of giving a diffraction image of a point source. Light from a parallel wave front is diffracted by the zone plate to a focal point in the detecting plane.

Unlike lenses, two or more zone plates can be made to overlap without seriously affecting the image forming capabilities of the individual plates. Thus the light gathering power of a zone plate can be made to exceed that which could be obtained by a lens under comparable conditions.

FIGURE 5 shows a support member 56 which may be a photographic film or glass plate. Formed on one surface are a number of zone plates such as the plates 57, 58 and 59. These plates, or some of them, may overlap as shown. The plates are positioned, as in the case of the apertures and lenses of FIGURES 1-3, to form a map of the stars, or some of the stars, in a selected region of the celestial sphere. The background area between zone plates must be opaque and may be made so by applying a suitable coating or, in the case of a photographic film or plate, by exposing this area. All of the zone plates have the same radii of transition and therefore the same focal length. The correlation peak is formed in the same way as in the lensed configuration of FIGURE 2.

The apparatus can be modified to use mirrors instead of lenses. In FIGURE 6 there is shown an opaque plate 61 on which concave spherical mirrors 62 and 63 are mounted. The detecting plane 26 is placed in front of the plate 61 as shown. Light from the various stars forms a correlation spot at the point 27 as before. At present, however, lenses are preferred to mirrors because suitable lenses are readily available at moderate cost. In the arrangement of FIGURE 3, off-axis aberrations present no problems, it being necessary only that on-axis rays be sharply focussed. Additionally, the use of mirrors involves the problem of the occlusion of a portion of the field of view, which problem is absent when lenses are used.

It would also be possible to construct the Fresnel zone plates with reflective instead of transparent zones but such plates would not only be more difficult to construct but would appear to offer no advantages.

The zone plates might also be formed on a spherical shell but the fabrication difficulties would appear to far outweigh any possible advantages. The zone plates are in effect very thin lenses, having virtually no thickness at all, so that aberrations due to off-axis focussing when using a planar mounting are insignificant. All things considered, zone plates having alternate opaque and transparent areas arranged on a planar mounting are preferred to either mirrors or lenses.

Referring now to FIGURE 7, there is shown schematically the overall arrangement of an embodiment of the invention. A box 71 contains most of the equipment, which will be more fully described. On one end of the

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box 71 there is shown a circular map or reference pattern 72 which may be any of the plates 21, 41, 46 or 56 previously described. The box 71 is mounted for rotation about a first axis, shown schematically by the line 73 representing a shaft. The shaft 73 and the box 71 are rotatable as a unit by an electric motor 74, the frame of which is supported by a gimbal ring 75, shown schematically as a rectangle. The gimbal ring 75 also supports the frame of a pick-off device 76 the rotor of which is also connected to the shaft or axis 73. The device 76 generates a signal indicative of the angular position of the shaft 73. The gimbal ring 75 in turn is mounted for rotation about a second axis 77, perpendicular to the axis 73. Such mounting is obtained by connecting the shaft or axis 77 to the rotor of an electric motor 78 the stator of which is fastened to a fixed frame of reference. Energization of the motor 78 rotates the gimbal ring 75 and the box 71 about the axis 77 and a pick-off device 79 generates a signal indicative of the angular position of the apparatus with respect to the axis 77. For convenience, displacement about the axis 77 is designated x displacement while displacement about the axis 73 is designated y displacement.

Referring now to FIGURE 8, the box 71 is shown by the dashed outline and all of the apparatus within the outline is contained within the box 71. There is shown the reference pattern 72 which may be any of the plates 21, 41, 46 or 56 of FIGURES 1-5. The plate 72 is mounted to be rotatable by an electric motor 81 which is shown schematically as driving a wheel or pinion 82 which in turn engages the periphery of the plate 72. A pick-off device 83 is rotated by the plate 72, for example through a pinion or wheel 84 fastened to the shaft of the device 83 and engaging the periphery of the plate 72.

Light from the star field is illustrated by two light rays 85 and 86 assumed to come from two separate stars. These rays pass through corresponding apertures or focussing elements in the plate 72 and through a circular shutter 87, the effect of which will be neglected for the present. The rays 85 and 86 intersect at the point 27 on the detecting plane 26.

The light received from stars in the celestial sphere, even when collected over a substantial area when using lenses or zone plates, is feeble at best. In order to increase the intensity of the received light, an image intensifier tube 88 is mounted with its receiving screen occupying the central portion of the detecting plane 26. One kind of image intensifier tube which is satisfactory is available as a commercial item from Westinghouse Electric and Manufacturing Co., Pittsburgh, Pennsylvania, and is designated model No. WX-4826. Such a tube receives an image on its input screen and, by using secondary emission techniques, presents a light amplified version of the input on its output screen. Resolution is more than adequate for present purposes.

A light sensitive device or sensor 91 is positioned adjacent to the tube 88 to receive the image from the output of the tube 88. This sensor is of the kind which generates two unidirectional voltages having amplitudes and polarities indicative of the power and position, in orthogonal directions, of the centroid of incident light, both of these voltages being zero when the centroid of illumination is at the center of the sensitive area. One such sensor suitable for use in the present invention is designated a Radiation Tracking Transducer, Model XY20D, manufactured by Micro Systems, Inc., San Gabriel, California. The output signals from the sensor 91 are passed to an electronic control circuit 92, to be more fully described, which generates suitable signals which control the x displacement motor 78 and the y displacement motor 74 so as to place the correlation spot in the center of the sensitive area of the sensor 91.

The spot of light produced at point 27 which represents the correlation function is not the only light to reach the detecting plane 26. As previously discussed in

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connection with FIGURES 1 and 2, light from each star passes not only through the corresponding aperture or focussing element to the point 27 but also passes through each other aperture or focussing element, reaching the detecting plane at various points such as the points 29 and 32 of FIGURES 1 and 2. These various points are not in general superimposed but are distributed more or less evenly over the detecting plane and constitute a background illumination from which the correlation spot must be distinguished. It is highly desirable to find some way of detecting or measuring not the absolute intensity of the correlation spot but the difference in intensity between the correlation spot and the surrounding background illumination.

The background illumination discussed above is analogous to the background illumination present when two photographic transparencies or a transparency and the original scene are compared. In connection with such comparisons it has been found that periodic defocussing or diffusing of the correlation spot into the background places an alternating component on the correlation spot intensity without greatly affecting the background intensity. Accordingly it is possible to examine this alternating component and obtain a signal indicative of the difference in intensity between the correlation spot and the background. Various expedients have been proposed for performing the periodic diffusing. For example, in one previously proposed arrangement the reference transparency is oscillated continuously about its optical axis, thereby providing the periodic diffusion.

In the present case the correlation spot is likewise periodically diffused. However, it is preferred to avoid the mechanical problems inherent in a continuously oscillating transparency. The image intensifier tube 88 requires electrical focussing and can easily be defocused. Accordingly, the control circuit 92 includes circuitry for generating a signal which is applied to the tube 88 to defocus the output image periodically. This defocussing places an alternating component, or signature, on the correlation spot intensity which component is detected and used to generate the various control signals.

FIGURE 9 shows how the various error signals are processed to perform the necessary control functions. The details of the electronic control circuit 92, previously mentioned in connection with FIGURE 8, are shown within the dashed outline. It will be recalled that the image intensifier tube 88 is periodically defocused. For this purpose there is provided a source of alternating current such as an oscillator 93 operating at a convenient frequency such as 100 c.p.s. The output of the oscillator 93 is applied to a frequency dividing and shaping circuit 94 which generates a voltage having half the frequency of the input. The latter voltage is approximately sinusoidal in form and is superimposed on the focussing voltage applied to the tube 88 so that the correlation spot presented to the sensor 91 is alternately sharply focussed and diffused into the background twice each cycle, or, in the present example, at a rate of 100 c.p.s.

It will also be recalled that the sensor 91 generates two unidirectional voltages, herein referred to as the x and y voltages, each of which indicates, by its polarity and amplitude, the direction and extent of the deviation of the centroid of illumination from one of the two coordinate axes. Because of the periodic diffusion of the correlation spot, each of these voltages has superimposed thereon an alternating component the phase and amplitude of which are indicative of the above mentioned direction and extent of deviation of the correlation spot, free from errors due to background illumination. The x signal is passed through an amplifier 95 to a synchronous detector circuit 96 which must be controlled or keyed at the 100 c.p.s. rate. Accordingly the output of the oscillator 93 is also applied to an amplifying and shaping circuit 97 which converts the voltage to a suitable waveform such as a square wave which in turn is applied to the synchronous detector

96. Therefore there is generated, on the conductor 98, a unidirectional error signal which is used to control a servo amplifier 99 which in turn controls the x displacement motor 78. The y signal is processed by a similar chain of components including the amplifier 101, the synchronous detector 102, the conductor 103, and the servo amplifier 104 which controls the y displacement motor 74.

The discussion so far has assumed that the reference plate 72 of FIGURE 8 is properly oriented about the optical axis. Detection and correction of rotational misalignment is accomplished with the aid of the previously mentioned shutter 87. The operation of such a shutter and its associated circuitry is described and claimed in the copending application of Lester I. Goldfischer, Serial No. 290,881, filed June 21, 1963, for Optical Correlator, which application is assigned to the same assignee as is the instant application. However, a description is also included herein for convenience.

As shown in FIGURE 10, the shutter 87 comprises a minor transparent area 111, for example one quarter of the total, while the remaining area 112 is opaque. The shutter 87 is mounted, as shown in FIGURE 8, closely adjacent to the plate 72 and is rotated at a substantially constant speed by an electric motor 113 which drives a pinion 114 engaging the periphery of the shutter 87. A generator 115 mechanically connected to the motor 113 and the pinion 114 generates an alternating voltage in synchronism with and at the rotational frequency of the shutter 87. This voltage is passed to the control circuit 92.

Referring now to FIGURE 11, there is shown schematically the plate 72 and the detecting plane 26. Consider first but a single star located in the upper portion of the field of view. A ray of light 121 from this star passes through an aperture or focussing element located in the upper portion of the plate 72 and falls on the detecting plane 26. Other rays of light from this same star, represented by the short arrows, fall on an opaque portion of the plate 72. If the plate 72 now be turned through a small clockwise angle, in the direction of the curved arrow 122, a different ray of light will pass through the aperture or focussing element with the result that the spot of light on the plane 26 will move slightly along a short clockwise arc, as indicated by the arrow 123.

Consider now only the light from a star located in the lower portion of the field of view, as illustrated by the ray 124. A small clockwise rotation of the plate 72 obviously causes that portion of the correlation spot associated with ray 124 to move slightly in the direction of the arrow 125.

FIGURE 12 illustrates the effect on the correlation spot of the rotation of the shutter 87, considering the entire field of view. In FIGURE 12, it is assumed that the plate 72 is misaligned in a clockwise direction. The shutter 87 is assumed to be rotating counterclockwise. The numerals 1-4 represent successive positions of the transparent portion of the shutter. In the first position, the shutter 87 masks everything except the upper quadrant, and accordingly at this time the correlation spot is shifted clockwise, that is, to the right as shown by the small arrow. At the second position, the spot is shifted upward; at the third position it is shifted to the left; and finally in the fourth position it is shifted downward. These shifts of position are further illustrated in FIGURE 13, wherein the numerals again represent the position of the transparent area of the shutter while the arrows represent the displacements of the correlation spot. In summary, with clockwise misalignment of the plate 72 and counterclockwise rotation of the shutter 87, the correlation spot rotates counterclockwise and lags the shutter position by ninety degrees.

By a similar analysis it can be shown that with counterclockwise misalignment of the plate 72 and counterclockwise rotation of the shutter 87, the correlation spot again rotates counterclockwise but now leads the shutter position by ninety degrees.

The rotation of the correlation spot occurs even when

the apparatus is properly aligned in x and y , in which case the spot rotates about the center of the detecting plane. Such rotation places another alternating component on the x and y signals generated by the sensor 91 which component also appears in the x and y error signals on the conductors 98 and 103 of FIGURE 9. The nature of these components is illustrated in FIGURES 14-17.

Referring now to FIGURE 14, the variation of the x error signal is shown for clockwise rotational misalignment of the reference plate 72 and counterclockwise rotation of the shutter 87. The abscissa is the angular position of the transparent area 111, indicated by the numerals 1, 2, 3 and 4 as in FIGURES 12 and 13. The ordinate is the x error signal. When the shutter is in its number 1 position, the correlation spot is shifted to the right and accordingly the x error signal is positive. At the number 2 position the x error is zero; at the number 3 position, the x error signal is negative; at the number 4 position, the error signal is again zero; and when the number 1 position is again reached, the error signal is again positive. Joining of these points forms the curve 131.

The curve 132 of FIGURE 15 similarly indicates the variation in the y error signal for clockwise rotational misalignment and counterclockwise shutter rotation.

The curves 133 and 134 of FIGURES 16 and 17 illustrate the variations in the x and y error signals respectively for counterclockwise rotational misalignment of the reference plate 72 and counterclockwise shutter rotation.

FIGURES 14-17 show that the x and y error signals contain alternating components indicative of the rotational error in the alignment of the reference plate 72. These components are at the frequency of rotation of the shutter 87. FIGURES 14 and 16 show that the x error signal for a counterclockwise rotational misalignment is displaced in phase by 180° with respect to the error signal for clockwise rotational misalignment. FIGURES 15 and 17 show that the y error signal exhibits a similar phase reversal for rotational errors of opposite sense. Therefore either the x error signal alone or the y error signal alone could be used to correct rotational errors. However it is preferred at present to utilize the information in both the x and the y error signals. Comparison of FIGURE 14 with FIGURE 15 and of FIGURE 16 with FIGURE 17 shows that in each case the y error signal lags the x error signal by 90° . Hence the information content of the two signals can be combined.

Referring again to FIGURE 9, the x error signal on the conductor 98 is applied to a phase shifting circuit 141 which shifts the phase of the alternating component by -90° to bring it in phase with the y error signal component. The output of the phase shifter 141 is applied to an adding circuit 142 where it is combined with the alternating component of the y error signal. The combined signal is applied to a synchronous detector 143.

The generator 115, it will be recalled, generates an alternating voltage in synchronism with and at the rotational frequency of the shutter 87. This voltage is amplified and its waveform converted to a suitable form, such as a square wave, by the amplifier and shaper 144, after which it is applied to the synchronous detector 143. Accordingly there is developed on the conductor 145 a unidirectional error signal indicative of rotational misalignment. This error signal is applied to a servo amplifier 146 which in turn controls the motor 81 to correct any misalignment.

To use the apparatus of the present invention, a region of the celestial sphere is first selected. A reference plate constituting a map of the stars, or the brightest stars, in this region is constructed, preferably using lenses as described in connection with FIGURES 2 and 3 or zone plates as described in connection with FIGURES 4 and 5. The reference is mounted, with the remaining apparatus, as shown in FIGURES 7 and 8. The frame of

reference of FIGURE 7 may be the frame of a space vehicle.

Light from the selected stars passes through the reference plate and alignment is maintained by the apparatus of FIGURES 8 and 9. The pick-off devices 76 and 79 of FIGURE 7 and the device 83 of FIGURE 8 generates signals which may be used as inputs to guidance or navigation equipment.

It is to be noted that the use of lenses or zone plates provides greater light gathering power and better resolution than can be obtained with simple apertures of any size.

Although a preferred embodiment of the invention has been described in considerable detail for illustrative purposes, many modifications will occur to those skilled in art. It is therefore desired that the protection afforded by Letters Patent be limited only by the true scope of the appended claims.

What is claimed is:

1. A map reference for a correlation star field tracker, comprising,
 - an opaque frame, and
 - a plurality of lenses having the same focal length positioned in a like plurality of apertures in said frame, said lenses and apertures being arranged in a pattern such that the optical centers of said lenses represent to a reduced scale the relative positions of a like plurality of stars in a selected region of the celestial sphere.
2. A map reference for a correlation star field tracker, comprising,
 - a frame including an opaque surface, and
 - a plurality of lenses having the same focal length positioned in a like plurality of apertures in said frame, said lenses and apertures being arranged in a pattern such that the optical centers of said lenses represent to a reduced scale the relative positions of a like plurality of stars in a selected region of the celestial sphere, said lenses being oriented with their optical axes perpendicular to said surface.
3. A map reference for a correlation star field tracker, comprising,
 - a substantially planar opaque plate, and
 - a plurality of lenses having the same focal length supported by said plate in a like plurality of apertures, said lenses being arranged with their optical centers in a pattern representing to a reduced scale the relative positions of a like plurality of stars in a selected region of the celestial sphere, the optical axes of said lenses being oriented parallel to each other and perpendicular to the plane of said plate.
4. A map reference for a correlation star field tracker, comprising,
 - an opaque plate curved in the form of a section of a spherical shell, and
 - a plurality of lenses having the same focal length supported by said plate in a like plurality of apertures, said lenses being arranged with their optical centers in a pattern representing to a reduced scale the relative positions of a like plurality of stars in a selected region of the celestial sphere, said lenses being oriented to have a common principal focal point.
5. A map reference for a correlation star field tracker, comprising,
 - a rigid opaque plate curved in the form of a section of a spherical surface, and
 - a plurality of lenses having a focal length equal to the radius of said surface and supported by said plate in a like plurality of apertures, said lenses being positioned with their optical centers forming a pattern representing to a reduced scale

the relative positions of a like plurality of stars in a selected region of the celestial sphere, said lenses being oriented so that the principal focus of all lenses lies at the center of said spherical surface.

6. A map reference for a star field tracker, comprising, a substantially planar supporting member having an opaque surface, and a plurality of zone plates formed in said member, said zone plates being arranged in a pattern representing the positions of a like plurality of stars in a selected region of the celestial sphere.
7. A map reference for a star field tracker, comprising, a supporting member having a substantially planar opaque surface, and a plurality of zone plates having the same focal length formed in said member, said zone plates being positioned in a pattern representing the positions of a like plurality of stars in a selected region of the celestial sphere.
8. A map reference for a star field tracker, comprising, a supporting member having a substantially planar opaque surface, and a plurality of zone plates having the same focal length formed in said member, each of said zone plates comprising a series of alternately arranged transparent and opaque zones, said zone plates being arranged in a pattern representing the relative positions of a like plurality of stars in a selected region of the celestial sphere.
9. A map reference for a correlation star field tracker, comprising,
 - a supporting member having a substantially planar opaque surface, and
 - a plurality of zone plates formed in said surface, each of said zone plates comprising a series of alternately arranged transparent and opaque zones, the corresponding radii of transition from transparent to opaque and vice versa being the same for all of said plates, whereby they have a common focal plane, said zone plates being arranged in a pattern such that their centers represent to a reduced scale the relative positions of a like plurality of stars in a selected region of the celestial sphere.
10. A star field tracker, comprising,
 - a supporting member,
 - a plurality of focussing elements having the same focal length supported by said member, the area between said elements being opaque, said elements being arranged in a pattern representing the relative positions of a like plurality of stars in the celestial sphere, said elements being oriented to have a common focal plane, a line perpendicular to said focal plane through the center of said supporting member defining an optical axis, means for mounting said supporting member for rotation about said optical axis, an image intensifier tube having input and output screens for receiving an image and generating an intensified version thereof, said tube being positioned with its input screen lying in said focal plane and being intersected by said optical axis, a radiation sensor positioned adjacent to said output screen for generating signals indicative of the amplitude and position of incident light, means for mounting said supporting member, said focussing elements, said image intensifier tube and said radiation sensor for rotation as a unit about each of two orthogonal axes, and means responsive to said signals generated by said sensor for aligning said supporting member about

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said optical axis and for aligning said unit about said two orthogonal axes for best correlation with said like plurality of stars.

11. A star field tracker, comprising, 5
 a supporting member,
 a plurality of focussing elements all having the same focal length supported by said member,
 the area between said elements being opaque,
 said elements being arranged in a pattern representing the relative positions of a like plurality of stars constituting a star field in a selected region of the celestial sphere, 10
 said elements being oriented to have a common focal plane,
 a line perpendicular to said focal plane through the center of said supporting member defining an optical axis, 15
 means for mounting said supporting member for rotation about said optical axis,
 an image intensifier tube having input and output screens for receiving an image and generating an intensified version thereof, 20
 said tube being capable of being focussed to provide a clear output image,
 said tube being positioned with its input screen lying in said focal plane and being intersected by said optical axis, 25
 a radiation sensor positioned adjacent to said output screen for generating signals indicative of the amplitude and position of incident light, 30

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means for periodically defocussing said image intensifier tube whereby light reaching said sensor is periodically diffused thereby placing first alternating components on the signals generated by said sensor,
 a shutter having a minor transparent area and a major opaque area mounted adjacent to said supporting member and rotating continuously about said optical axis whereby said signals generated by said sensor contain second alternating components,
 means for mounting said supporting member, said focussing elements, said shutter, said image intensifier tube and said radiation sensor as a unit for rotation about each of two orthogonal axes,
 means responsive to said first alternating components for aligning said unit about said two orthogonal axes for best correlation with said star field, and
 means responsive to said second alternating components for aligning said supporting member and said focussing elements about said optical axis for best correlation with said star field.

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RALPH G. NILSON, *Primary Examiner.*

J. DAVID WALL, *Assistant Examiner.*