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(19) (CA) **CANADIAN PATENT** (12)

(54) Optical Tracker and Dynamic Pointing

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Abstract of the Disclosure

An optical scanning apparatus is disclosed which comprises an optical detector sensitive to optical radiation, which detector provides an electrical analog signal representative of the detected optical radiation. A scanning means for scanning optical radiation with an adjustable field of view directs the scanned radiation to the said optical detector. An analog-digital converter responsive to the electrical analog signal provided by the detector which produces digital information representative of the information content of the detected output radiation is stored in a memory for receiving the output of the analog-digital converter. Processing means for processing the digital information stored in the memory, display means for visually displaying the digital information stored in the memory, and means for updating the information stored in the memory with digital information representative of subsequent scans of the field of view are also provided.

This invention relates to an optical scanning, tracking, surveillance and laser weapon firing apparatus and system and subcombinations thereof.

The need for accurate location and surveillance of a scanned moving object manifests itself in a number of military and civilian contexts. The system to be described will be reviewed in a number of specific contexts, but it will readily be understood that the system and apparatus according to the invention can be considered for use wherever
10 there is a problem of precise location and tracking of a moving object which is sightable by optical (including ultra-violet and infra-red) means.

For example, improved precision in the firing of guns and rockets requires accurate angular information (both azimuth and elevation) for control of the firing of such weapons. A number of the previous proposals for scanning and tracking are limited by reason of inferior angular resolution, difficulty of adaptation to night operation or operation in fog, lack of capability for passive
20 operation only, problems associated with the display of the received information, problems in coupling to manual or automatic tracking devices, etc. A drawback with many prior systems is their inability to function unless the equipment stays in a fixed (usually land borne) position, which prevents their utility in ships, airborne equipment, etc.

It is an object of the present invention to provide an optical scanning, tracking, surveillance and weapons firing system and apparatus which avoids some of the problems associated with previous equipment proposals.
30 It is a specific object to provide such a system and apparatus

in which at least limited movement of a vehicle in which the apparatus is used can be tolerated. It is a further object to provide alternative active and passive modes of operation of such system and apparatus.

10 In its broadest aspect, the present invention provides optical scanning apparatus comprising an optical detector sensitive to optical radiation and providing an electrical analog signal representative of the detected optical radiation, scanning means for scanning optical radiation within an adjustable field of view and directing the scanned radiation to the detector, an analog-digital converter responsive to the electrical analog signal provided by the detector and producing digital information representative of information content of the detected optical radiation, display means for visually displaying the digital information stored in the memory, a memory for receiving the output of the analog-digital converter and storing the digital information, processing means for processing the digital information stored in the memory, and means for
20 updating the information stored in the memory with digital information representative of subsequent scans of the field of view.

The present invention is intended for optimum application in situations in which the field of view is confined to a relatively small angle (e.g. $2^\circ \times 2^\circ$). It is accordingly proposed that the apparatus and system according to the invention be used in conjunction with other scanning, tracking, locating and positioning apparatus that can locate the target object within a viewing angle corresponding
30 to the field of view of the system according to the invention.

It is further proposed that in order to avoid the disadvantages associated with night operation, fog, etc., that the sensing capability of the apparatus extend into the infra-red wavelength range (e.g. 8-13 μ m using MCT or PbSnTe detector, or 3-5 μ m using an InSb detector) and much of the description to follow will presume that infra-red sensing and detecting apparatus is employed. However, it is to be understood that in situations in which night viewing, fog, etc. are not required, the sensing and detecting equipment could be selected for use in monitoring radiation in the visible range or even the ultra-violet range, if so required by any particular application.

In active mode, it is proposed that the apparatus include a directed laser beam whose reflected radiation from a target is sensed and detected. However, it is sometimes desirable that the monitoring system operate in passive mode, i.e. sense and detect only that radiation produced by the target itself. For example, it may be desirable that ships be able to operate under radio-silent and radar-silent orders so as to avoid long-range detection.

A preferred embodiment of the tracker according to the invention is directed to the detection of a target within a spatial cell of a few degrees in elevation and azimuth (a typical one being 2° x 2°). A search system (radar, infra-red or optical) can be used to provide coordinates to center the tracker along the cell axis and from then on, after acquisition, the tracker locks itself on the target. The optical head scans the full observation cell continuously and the signal is fed on a push-through memory of small size. This memory is read rapidly for presentation on a suitable

display, e.g. a television-type display on a screen monitor. From the display, the operator can possibly obtain target identification and/or make a choice of a single target in a cluttered field. Target tracking can be done for example manually with a joy-stick looking at the target movement on the display screen, or through a penlight designation on the monitor screen, or through the memory itself.

10 The optical system can be designed to illuminate the tracking field with a continuous wave laser and thus provide an active "signature" from the target using the reflected light. The system can be designed to have no parallax and, using two detectors, both active and passive signatures could be obtained simultaneously. They could be subtracted or added before loading the memory, or else loaded alternately in the memory and shown on the screen. A colored display could also be used to show both images simultaneously.

20 One advantage of the system is the large observation field presented to the operator. This should permit the relaxing of rigid stabilization requirements (of importance at sea). A differential sensor can be used to record the very precise movement of the sensor between frames (or better, between the moments where the target itself is picked by the sensor) and this information could be used to put an electronic bias on the display so that the selected target point will appear at a very precise and stable position. The information could also be used to obtain exact target coordinates describing the target
30 position and movement.

A preferred embodiment can be described generally as follows:

An optical detection unit, similar to a telescope, is used to focus the radiation on a far infra-red detector. A mechanical scanner centers the field to be scanned within 360° in azimuth and say, some 70° in elevation. Around this reference line, an optical field of say $\pm 1^\circ \times \pm 1^\circ$ is looked at and the temperature variations in this field are transformed into electrical pulses through a detector/amplifier unit. If passive operation only is desired small mirrors (or prisms) near the focal point can be used to scan the tracking cell. The detector signal, after amplification, is sent to an analog-to-digital converter and a buffer, the sampling action being determined by position reference pickups on the moving head to ensure that the sampling of the digitized point is independent of any scanning speed. The digital signal is accumulated line by line in a buffer and dumped in a circulating push-through memory. The memory unit can be relatively small (about 5K bytes for a total field-of-view of $2^\circ \times 2^\circ$ and an instantaneous field of 0.5 mrad). The rapidly circulating memory is read by a pick-up, and the signal after passing through a digital-to-analog converter is fed to a screen display, with proper X and Y positioning, at a rate of 20-30 frames per second. A flicker-free display is obtained with excellent grey scale contrast.

After the tracker is positioned around the target, as soon as the detection is made, the target point appears on the screen, and can be followed and centered by a selected means, such as one or more of the following means:

- (a) One target point could be selected and centered on the screen through a manual displacement of the central optical axis using a joy-stick.
- (b) A penlite on the screen with automatic feedback could be used to designate one target, and from the spot position on the screen a feedback loop could be used to center the optical axis of the system.
- (c) Using the memory itself any target designated by a penlite could be located exactly in an additional bit plane and this exact location could be read to provide very precise coordinates of a many target field without having to center the optical axis. The memory itself could be used to center a single point on the optical axis.

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The advantages of this last feature are significant in an environment where fine stabilization is difficult and expensive (e.g. at sea). For example, it may be desirable that ships be able to operate in radar and radio silence to avoid detection at very large ranges in threat conditions.

20

On the other hand, the sensing station may itself be a target, since it may not be able to avoid producing infra-red radiation, and may thus be vulnerable to infra-red seeking missiles, for example. Active countermeasures may require accurate missile detection.

It is therefore desired to utilize the laser beam for active target detection, and optionally, for target destruction. One of the most difficult problems is the pointing of the laser very accurately so that the narrowest beam and the maximum energy concentration are realized.

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The only technique previously known to achieve an extremely accurate positioning is through a slave system

in which one unit (search or track) gives out the target coordinates very precisely and these coordinates are used to position the laser beam. Any calibration error between the angular position of one of the two instruments means that the target is missed when the error is larger than about 0.5 mrad. This is even more difficult in an environment such as at sea where a platform stabilization better than 0.5 to 1 mrad is very difficult and expensive. In most previously described cases, there is no coordination
10 between the search/track unit and the laser firing so that damage assessment is difficult, if not impossible.

The principles of this aspect of the invention can be summarized as follows: A small space cell (ex. $2^\circ \times 2^\circ$) is scanned in elevation and azimuth by a mirror outside the telescope unit. The signal is fed on a push-through memory, the content of which is refreshed with each frame scan. The memory itself is scanned very rapidly and an image of the track field is displayed e.g. in a flicker-free way on a screen. Using at least some of the same optics
20 as used for optical tracking, a continuous wave laser can be used to illuminate the space cell and reflected signals from the target can be detected.

Once the target is detected and identified, it is possible to predict the target position in the next frame scan very exactly, and when passing over that position, it is possible to fire a pulsed laser of any power level with a very good probability of success. The image on the display can be frozen in the memory after firing, if desired, and an assessment of the damage can be done immediately.
30 If the target is moving, it should be possible to follow the path by processing the memory content of consecutive

frames and thus track a single target, or one target that has been designated among many using, for example, a penlite. With this information, it should be possible to include in the prediction the target movement, as well as any movement of the tracker to center the target in the optical field, and to fire the laser at the exact point in the optical field where the target will be. A third correction should be possible to cope with any fluctuation in the platform. Assuming a stabilization of 3-5 mrad is possible, fine sensors on the platform can measure the continuous movements between frame scans - there would be no need for long-term accurate reference - and feed that correction to the prediction unit. The target point could be taken as a reference to apply the correction so the point should appear without any blurr on the screen, except for the changes in the optical axis orientation or the target movement itself.

The present invention offers a unique means of positioning a laser beam on a target without centering an optical system, or bore-sighting it to a second search/track unit. Ranging can be done while scanning, and distance can be obtained on more than one target in the field-of-view. Damaging by laser weapon - if feasible - can also be achieved effectively.

The invention will now be described with reference to the accompanying drawings in which:

Figure 1 is a schematic view of the optical head according to one embodiment of the present invention.

Figure 2 is a schematic view of an alternative optical head for use in an embodiment of the present invention.

Figure 3 is a schematic block diagram showing the signal processing system for use in association with the optical head of Figure 2.

10 In Figure 1, a scanning mirror 10 is shown pivotally mounted between upright support posts 12 and 14. The angular position of the mirror 10 (i.e. angle of elevation of the scanning or scanned beam) is adjusted by elevation drive motor 28. An elevation angle position sensor may suitably be incorporated into the same structure generally indicated by reference numeral 25. The support posts are mounted on a rotatable turntable 16 having a central aperture 18 through which light received from the scanning mirror 10 can pass through a lens 20 to optical detector 22. The turntable 16 is driven by a servo-drive motor 24 and the angular position of the turntable may be sensed by a separate sensing element 26 or instead by a sensing element (not illustrated) associated directly with the drive motor 24.

20 It is contemplated that the scanning mirror 10 will be oscillated so as to provide a scan of the field of view within a narrow spatial range, e.g. $2^\circ \times 2^\circ$. For this purpose a mechanical oscillator 25 is shown schematically in Figure 1 for oscillating the mirror rapidly within say 1° of a central reference axis.

The overall mounting for the unit illustrated schematically in Figure 1 is not shown but it is contemplated that the unit would be gyroscopically mounted if located on a moving vehicle, for example. This would tend to avoid inaccurate azimuth or elevation determinations from the scanning unit.

30 The optical head of Figure 1 is capable of detecting passive radiation from a target. However, it may

be desired to direct a beam of radiation at the target and to monitor the reflected radiation. For such purpose, the apparatus schematically illustrated in Figure 2 is preferable to that illustrated in Figure 1. In Figure 2 the scanning mirror 10 is shown located above telescope mount 30 which should be isolated from the scanner mount 32 so as to avoid transmission of any vibrations or the like from the scanner mount. On the isolated mount 30 a telescope generally referred to by reference numeral 34 associated with a prism structure generally referred to by reference numeral 36, and a laser 38 are mounted. The optical axis is folded by means of the prism structure 36, which is thus adapted to pass received radiation from the mirror 10 to the telescope 34 and adapted to transmit to the mirror 10 (and thence outwardly to the target) radiation generated by the laser 38. To this end the prism structure 36 is provided with an outer set of prismatic reflectors 40 which pass radiation received from scanning mirror 10 through the telescope 34 to optical detector 22. An interior space 42 is provided within the prism structure 36 through which radiation received from laser 38 may be directed via prism reflector 44 to the scanning mirror 10 and thence to the target. A masking element 43 is provided within the telescope 34 to block any stray radiation from the laser 38. The radiation provided by the laser 38 may simply be scanning radiation intended to be reflected back from the target received by the scanning mirror 10 and directed to the optical detector 22. Alternatively, if the laser 38 is a very high powered laser, the beam provided may be of sufficiently high intensity to damage the target, in which case the laser 38 in conjunction with the optical head constitutes a weapon.

A principal disadvantage of the arrangement of Figures 1 and 2 is that the scanning mirror 10 is relatively large, thereby giving rise to difficulties in generating a rapid and precise mechanical scanning action. A small mirror (not shown) positioned for oscillation just before the focal plane should enable the scanning rate to be increased. However, oscillation of the larger mirror 10 in the embodiment of Figure 2 does entail these advantages:

- 10 (a) The detector is always on (or very close to) the optical axis of the telescope; therefore, off-axis aberrations do not affect the performance of the system. Simple and low cost telescopes can be used. Chromatic aberrations are eliminated by the use of reflective optics. Since the detector is outside the scanning head, its signal is not carried through slip rings, possibly generating additional noise.
- (b) When properly adjusted, the laser beam should coincide with the optical axis of the system, wherever it is directed. There is no parallax problem. This property
20 is the basis for the laser weapon firing to be discussed below.
- (c) The image is always erect. If instead a focal scan were to be used, the image would rotate with the azimuth position, and it would be necessary to compensate exactly and continuously in the display and the operator control or programming circuitry for that image rotation. Such disadvantage might be less important in the tracking mode, but proper inversion compensation would be required for proper tracking.
- 30 (d) The design is very versatile in the choice of detector size, operating wavelength and detector mixes. For

example, the following modes of operation are possible:

Single Detector - This option includes a single detector of a given size within a given wavelength band. A filter can be used for further selection.

Multi-Spectral - This option permits the choice of various detectors covering different wavelengths.

10 This is especially worthy of consideration if one detector is matched to a laser (CW or pulsed) while a second one provides a passive image.

Multi-Spatial - This option compensates for the scan speed in, for example, the passive surveillance mode. A small detector could be surrounded by a much larger one at the focal plane. A low-resolution moving map presentation could be shown on the display: if any anomaly or target were detected, a sector scan at high resolution could provide proper identification.

20 Figure 3 illustrates schematically an associated signal processing and control system for use with the optical head of Figure 2 (it being understood that a similar system could be used in conjunction with Figure 1, the major difference being that the system of Figure 3 includes means for controlling the operation of the laser unit 38 whereas no such unit is illustrated in Figure 1 and thus that part of the apparatus of Figure 3 would not be required for use in conjunction with the Figure 1 optical head).

30 The scanning unit of Figure 2 is indicated generally by the reference numeral 46 in Figure 3, the laser unit 38, however, being illustrated separately for purposes of explanation. The received optical signal and any transmitted optical signal are processed through the

scanning unit 46, the signal paths being shown in further detail in broken lines in Figure 2. Three essential types of information are generated from the scanning unit 46, namely the optical signal received, the angle of azimuth, and the angle of elevation. For coarse angular information, separate azimuth sensor 26 and elevation sensor 50 are illustrated in Figure 3, although a combined sensing unit for both azimuth and elevation might conceivably be provided in an appropriate case. It will be further appreciated that
10 the transient scanning position of the scanning mirror both in elevation and azimuth must be determined as well as the average angular position, the former being governed by the oscillation of the scanning mirror 10 by the mechanical oscillator 28. The transient scanning azimuth and elevation information will generally be detected in association with the detection of the optical information, and passed to the signal-processing equipment as raster information along with a brightness or intensity signal.

An analog-digital converter 58 receives as an
20 input the sensed optical information and at least the scanning position information or raster information which has been received from scanning unit 46 by the optical detector 22 and which may be amplified by an amplifier 60 prior to passage to the analog-digital converter 58. (Because of the difficulty in operating directly upon the analog signal, the analog-digital converter 58 provides the essential angular and optical information in digital format.)

The digital information is fed sequentially to
30 a push-through memory 62, which may receive the information at a relatively slow or even irregular input rate. If the

image field is progressively changing and is scanned sequentially, each new line being entered in the fully loaded memory pushes the oldest entry off the memory (moving map presentation). If, however, the image field is fixed (sector scan), whenever the oldest entry line is scanned again, a new line is fed in, and the oldest drops out; the replacement proceeds until a fully refreshed image is available in the memory.

10 Although the memory loading can proceed at a random rate, the reading of the memory can be made at a very fast rate, even one compatible with a television raster. One thus obtains on such display a flicker-free image of very high quality as well as a unique tool for advanced signal processing.

20 Since the digital memory 62 can accommodate a slow or irregular rate of input, while the output can be as fast as desired, the possibility arises of using the azimuth and elevation axis information to command the sampling and synchronization. In this way, assuming no vibration, any given point can be referred to an absolute space position. Two encoders 52, 54 are used with fine angular resolution, and the encoder marks are simply counted relative to an arbitrary reference point. Thus, any identified point in space can be relocated precisely once the instrument is operating. This process is independent of scanning speed, overshoot and speed variations. The image on the display (to be described below) is always linear in azimuth and elevation. This feature is especially important for co-ordinate transfer in a fire control role for laser 38, for
30 example.

To this end, the markers from the encoders 52, 54 are added in a programmer 72 and this information is used for the azimuth and elevation drive control, provided by azimuth and elevation drive control units 24, 25 respectively. The elevation encoder also provides sampling command and synchronization references in unit 56 for the required analog-to-digital sampling. This information is passed by unit 56 to analog-digital converter 58. The programmer 72 itself is controlled by either a manual input
10 via operator control unit 68, or by an automatic servo loop including signal-processing and computational unit 72.

Horizontal displacement may be controlled through the programmer 72 by the vertical position of the mirror
10 and the angular width of the vertical scan line. It is thus possible to have an optimum line-to-line match strictly tied to the vertical scanning position independent of the vertical scanning speed and its fluctuations. This is quite useful whenever two detectors of different horizontal width are used in the instrument (zoom effect);
20 the horizontal speed may thus be automatically controlled by the selection of any one detector.

The display unit is illustrated generally by reference numeral 64 and may include an appropriate digital analog converter for the continuous presentation of the received and stored optical information. The display unit 64 may take its input directly from the push-through memory 62 or from a stable storage medium such as tape or disc storage 66 whose recorded information has been obtained from the push-through memory 62. The storage facility
30 may be useful for later interpretation and evaluation although of course if the system of Figure 3 is being used

actively for tracking a target and possibly controlling weapons brought to bear on such target, the tape or disc storage 66 would not be used and the display 64 would be fed directly through the push-through memory 62.

Since the memory 62 when loaded, can be read at any speed, an obvious choice for display is a format compatible to commercial television, so that commercial equipment could be used for recording or displaying the memory content. The digital data in the memory is thus
10 preferably read in a television scanning format, converted to analog and displayed directly. In advanced signal processing, false or pseudo colors may be used to improve detectability of targets: the processed image can be fed to a regular color television unit.

The presentation on the display may be varied depending upon the mode of operation. For example, the following display presentations may be provided:

- (a) A Moving Map type presentation showing the horizon line around, say, a ship, moving very slowly on the
20 display.
- (b) A Sector Scan type presentation, where a horizon sector of, say, 10° , centered at any azimuth point, is displayed continuously while being scanned. The information regarding this sector could be refreshed rapidly, say every few seconds.
- (c) A Tracking Mode where any space sector (e.g. $2^\circ \times 2^\circ$) around, say, a ship (using for example -10° to $+20^\circ$ elevation; 360° azimuth) can be imaged on the display and refreshed every few seconds. This approach should
30 permit a good quality flicker-free presentation of the full tracking field at every instant, and permits the following means of operation:

MANUAL TRACK: This could be achieved using a simple joy-stick to center the target as seen on the display.

Selection of one of many targets should be feasible.

DISPLAY TRACK: Using the display itself, one target could be designated in the field by a penlite sensor or a movable crosshair indicator, and the system optical axis could be moved automatically to center that target on the display and in the field of view.

10 MEMORY TRACK: Using the digital memory and its inherent ability for signal processing and data location, it is possible to conceive a simple hands-off operation, wherein a well-identified target point in the memory is displaced towards a central position through appropriate signal processing and automatic servo-displacement.

20 POSITION AND RANGE INDICATION: Although not an imagery presentation, it would be relatively easy to use the memory for obtaining the exact position of a target anywhere in the tracking field. The target could be designated on the scope and precisely positioned in the memory, or else the memory could do an automatic target selection. If the instrument orientation is well established, very accurate digital values for azimuth and elevation should be available for fire control and displayed on an indicator. Values for range could also be displayed if a laser range finder is used. If many targets appear in the tracking field, the coordinates of each could be displayed in sequence or on a series of digital indicators. Angular rates and range rates

30 could also be obtained.

As suggested above, the interaction of the operator with the display information is variable depending upon the

kind of display presented and the kind of control that is desired over other operations. Accordingly, a wide variability of system and circuit design can be provided to govern these interrelationships. Generally, the operator control unit 68 permits the operator to receive information from the display 64 and optionally to control the display in some manner as by stopping the displayed optical picture at a specific point in time (for example, for the purpose of evaluating damage done to a target).

10 But the information provided by the push-through memory 62 may instead be automatically processed by the signal-processing and computational unit 70, or this unit 70 may be wholly or partially under the control of the operator via control unit 68.

The computational unit 70 may include circuitry for the provision of target enhancement and false target elimination. Means for improved target visibility for an operator subject to fatigue can also be provided by the use of false or pseudo color, or by moving target designation.

20

An exemplary system may include the following system parameters:

MOVING HEAD CHARACTERISTICS

Clear Aperture through Mount	8 in Dia.
Elevation Limits	-10° to +20°
Azimuth Limits	none
Maximum Elevation Tracking Rate	3 rad/s
Maximum Elevation Acceleration	560 rad/s ²
Maximum Azimuth Tracking Rate	.15 rad/s
30 Maximum Azimuth Accelleration	85 rad/s ²
Maximum Azimuth Slew Rate	300°/s, 5 rad/s

Elevation Incremental Sensor	100 lines/°
Azimuth Incremental Sensor	100 lines/°
Elevation Position Accuracy	±.01°/0.17 mrad
Azimuth Position Accuracy	±.01°/0.17 mrad

OPTICS

Cassegrain Reflecting System	
Primary Minor Diameter	8 in
Focal Length	12 in
Effective Focal Ratio	f/1.9
10 Focus	infinity
Telescope Limiting Resolution	0.1 mrad

DETECTOR

Atmospheric Window	8-13 μ
Cooling Temperature	77°K
Photovoltaic Type	PbSnTe
Element Size	0.15 ± .02 mm ²
Cold Shield	32° ± 2°
Cooled Optical Filter (λ at 50%)	8-12.4 μ
D* (10.6 μ , 20 KHz, 1 Hz, 32°)	2 x 10 ¹⁰ or better
20 Optimum Sensitivity Range Wavelength (T 85%)	8.4 to 12.0 μ
Preamplifier Gain	200
Noise Figure	2.0 dB or better
Bandwidth	5 Hz to 150 KHz

DIGITAL PULSE MEMORY

Elevation Sampling Resolution	50 elements/°
Azimuth Sampling Resolution	50 lines/°
Elevation Memory Format	128 elements/line

Azimuth Memory Format	≈ 485 lines
Detector Level Format	6 BITS
Input Line Frequency	~60 lines/s
Input Frame Time for 9.6° Field of View in Azimuth	8 s

TV DISPLAYS

Full Scan Picture Format (Full Memory)	2.56° x 9.6°
Horizontal Line Rate	15750/s
Vertical Frame Rate	30/s
10 Line Interlace	2:1 positive
Geometric Picture Distortion	less than 1.5%

IMAGING PERFORMANCE

Resolution at the display	1.2 c/mrad
Sampling Density	2.86/mrad
Optic System IFOV	.5 mrad

Such system would be capable of the following performance:

(a) Station-Keeping/Collision Avoidance

360° azimuth coverage / 2.56° elevation
20 Moving map display / 9.7° x 2.56° sector scan
Time to complete one rotation in azimuth: 5 min

(b) Tracking

2.56° x 2.56° space cell coverage
Centered from -10° to +20° elevation / 360° azimuth
Time to update the space cell display: 2.2 s

Circuit and mechanical details for the blocks of Figure 3 will vary widely from case to case and will therefore not be further described. Their design will be achievable, for any particular application, by a person skilled in the art.

The operation of the system of Figure 3 will be further elaborated with reference to some of the operational modes referred to above:

1. Station-Keeping and Passive Surveillance

Passive surveillance at sea covers the search and track of any object, flying or floating, while the radars are kept silent. Station-keeping is a more restricted activity the aim of which is to operate many ships effectively while maintaining proper position; collision avoidance is of extreme importance whenever ships have to operate close together or are in a closing course. Floating objects on the sea surface are generally moving at a relatively slow pace, so functions like station-keeping or collision avoidance can be performed effectively using a scanning instrument operating at low speed.

In the above-mentioned exemplary instrument, the operation of scanning mirror 10 for an 8-inch telescope would be limited to an oscillation rate of about 30 Hz (i.e. 60 lines per second). With 50 lines per angular degree, 5 minutes would be required to cover the full horizon around the ship; the horizon line being displaced at a rate of 1.2° per second. Assuming a display coverage of 485 lines with 128 elements per line, a sector of the horizon of $9.7^\circ \times 2.56^\circ$ would be visible shifting around at a rate of $1.2^\circ/\text{s}$ in a moving map presentation with a sampling frequency of about 2.86 cycles/mrad. Such a system would give 4.2 ft resolution at 1 mi, 16.8 ft at 4 mi and 42 ft at 10 mi. With an adequate signal-to-noise ratio, a patrol boat should be identifiable at more than 1.5 mi and a destroyer at more than 5 mi.

The limit imposed on the scanning speed of the horizon line by the heavy mirror displacement could be eased, if two detectors were used - a larger detector element for coarse detection and a finer one used for identification in a sector scan mode. For example, if the horizontal resolution is decreased by a factor of 20, the entire horizon will be scanned in about 18 s, giving good detection range (the larger cell noise being possibly compensated by the narrower bandwidth), and good identification should be possible of close-by vessels as well as excellent protection against collision. Whenever detection occurs, it would be possible to switch to a high resolution sector scan (zoom effect). The best operating conditions in such a compromise would depend upon the operational and tactical requirements.

The sector scan could be used to cover one segment of the horizon of 485 lines. At a rate of 60/s, this segment could be refreshed once every 8.08 s by using a horizontal scan of a triangular or sinusoidal form. This should be more than adequate for following a manoeuvring ship nearby. High repeatability could be insured through the stability of the position encoders. If the surrounding ships are well identified, it is possible that some range information (perhaps imprecise) could be obtained from the size of the ship as shown on the display.

2. Tracker Mode (Passive)

It is preferable to use the information of a search radar, or that of an infra-red search unit, to position the instrument of the above-described exemplary system within a couple of degrees of the target, and, whenever the target appears on the display, to perform the

fine tracking task using the present invention. The ability of the system to present a very steady image of the full tracking field is an obvious advantage in the case of multiple targets or where it is necessary to precisely follow the effect of some counter-attack on the target.

10 The tracker in the above-described exemplary unit will cover a field of $2.56^\circ \times 2.56^\circ$ centered on any point from -10° to $+20^\circ$ elevation in a 360° azimuth. The tracking cell image will be updated every 2.2 s, and an angular displacement of the target of, say, less than $0.1^\circ/\text{s}$, would ensure adequate tracking capability. This limit may be acceptable for an attacking missile manoeuvring slowly or for a helicopter being brought in for docking. In those cases where the azimuthal rate is slow enough, the dynamic firing of laser can be used in connection with the tracking mode (see below).

20 By the addition of a two-dimensional scanning mirror near the focal point, it would be possible to accelerate considerably the scanning rate up to say, 100 frames per second. It would be possible in this case to follow a target at the speed limit of the scanner drives. The display could be direct on a screen without digital memory. Some means to correct for the gradual rotation of the imagery as a function of the azimuthal position would be required in the servo command, if not on the display, to ensure proper tracking capability.

3. Laser (Active Mode)

30 The optical head design offers a unique capability for pointing a laser along the optical axis of the system at any instant during the scanning process. This means that the full laser energy can be concentrated on the

target without any energy spreading to cope with out-of-alignment difficulties. Similarly the detector and telescope can match closely the beam spreading of the laser, thus reducing the overall noise.

Specifically a CW laser could be installed, adjusted parallel to the optical axis and operated to illuminate the target, thus generating an active target signature. (Backscattering might limit the usefulness of this approach.) A CW or quasi-CW laser could also be used
10 in a target marker or designation role (see below).

The most immediate use of the laser in this mode is to obtain the range either for station-keeping or while tracking. The coincidence of the laser beam with the system optical axis and the prediction of the firing instant permits a great economy of laser power as well as protection against the laser beam being intercepted through multiple pulses and large beam spreading. Means can also be provided to indicate on the display exactly where (or when) the laser pulse was released. Ranging on ships during sector scan
20 sweeping is quite easy and would require a single pulse of limited energy and, if in the nanosecond length range, the pulse would hardly be detectable.

A second characteristic of the system is the possibility of predicting within the memory the exact location of the target. It is thus feasible to control the firing instant of the laser through the memory while scanning: this process is called dynamic firing. After proper location of the target in the digital memory, either through designation on the display or automatic designation in the memory
30 itself, a pulsed laser could be fired during the following scan at the exact moment when the optical axis crosses the

target. The full energy of the laser could thus be delivered directly on target without any appreciable spoiling and without a difficult boresighting of two independent pieces of equipment.

A second point to be mentioned is that proper signal processing in the digital memory not only permits exact firing at the proper point, but should also permit fine correction for the following:

- (a) Optical Axis Displacement while continuously tracking.
- 10 (b) Target Movement, since after a few scans and adequate memory processing it would be possible to predict the target position for the next few scans.
- (c) Platform Movement, since sensitive analog position sensors could be attached to the instrument supporting platform to provide fine position corrections relative to the exact instant when the target was scanned. This correction could be applied firstly to the display presentation (x and y stabilization) so that a selected target would appear very steady in the field being displayed, and
- 20 secondly, to the memory processor for accurate target location prediction even if the platform is slightly unstable. This platform movement correction on the display and in the memory is very important since an optical sea-borne system might otherwise require very accurate platform stabilization at an excessive cost. If the stabilization requirement can be relaxed by a factor of 5 or 10, the cost saving will be very large.

4. Dynamic Firing as a Weapon

The invention raises as a corollary the question of

30 the feasibility of using a very powerful laser beam in a defensive role for destroying an incoming attacking vessel,

for blinding the pilot or for any other strong interaction with the attacker. It would be necessary in any case, to position very accurately the laser beam on the target and avoid beam spoiling as much as possible. The potential of the dynamic firing of the laser while tracking is unique because it offers the possibility of combining in a single instrument observation of the tracking field as well as control of the laser beam position. Damage can also be assessed immediately in the next scan.

10 A possible approach would be to use a laser which is transparent to its own radiation when not excited (e.g., the TEA CO₂ laser). A powerful system including an oscillator, a preamplifier and a power amplifier could operate in a ranging mode using only the output of the preamplifier through the idling power amplifier. Whenever damaging is intended, the overall system would be fired in a dynamic mode, and the full laser beam could be directed without spoiling and with great precision, on the target.

5. Target Marker

20 A major threat against naval ships is the low flying missile, or the sea skimmer. The best defence and active countermeasure appears to be a direct attack against the missile itself after detection. The possibility of "marking" the missile with a laser beam (CW or quasi-CW) and using an anti-missile-missile guided by the reflected light is a potential approach.

30 The system described above offers a unique possibility of accomplishing the foregoing. A general characteristic of an incoming missile is its very slow angular rate relative to the target. Using focal scan, the missile is kept centered in the display and a laser beam is directed through the

optical axis directly onto the missile itself. The imagery on the display will show immediately if the beam is really on target by the strong reflection. It should thus be possible to maintain a laser beam on an incoming missile with minimum spoiling and, constantly through the display, be sure of the effectiveness of the laser marking as well as that of the anti-missile-missile.

10 Using a dichroic mirror to separate the passive imagery from the laser return, a quadrant detector could be used for controlling the tracking head, when the laser return is properly detected. The passive imagery would provide an overriding means of recuperating the target, if it escapes from the quadrant detector field of view.

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. Optical scanning apparatus comprising
 an optical detector sensitive to optical radiation
and providing an electrical analog signal representative of
the detected optical radiation,
 scanning means for scanning optical radiation
within an adjustable field of view and directing the
scanned radiation to the detector,
 an analog-digital converter responsive to the
electrical analog signal provided by the detector and pro-
ducing digital information representative of information
content of the detected optical radiation,
 a memory for receiving the output of the analog-
digital converter and storing the digital information,
 processing means for processing the digital informa-
tion stored in the memory,
 display means for visually displaying the digital
information stored in the memory, and
 means for updating the information stored in the
memory with digital information representative of subsequent
scans of the field of view.
2. Apparatus as defined in claim 1, wherein the
display means comprises a television picture tube.
3. Apparatus as defined in claim 2, wherein the
processing means includes means for adjusting the field of
view and maintaining a detected target within the field of
view.

4. Apparatus as defined in claim 3, additionally comprising a laser optically coupled to the scanning means and adapted to direct output radiation towards a detected target within the field of view.

5. Apparatus as defined in claim 4, wherein the scanning means includes an oscillating mirror.

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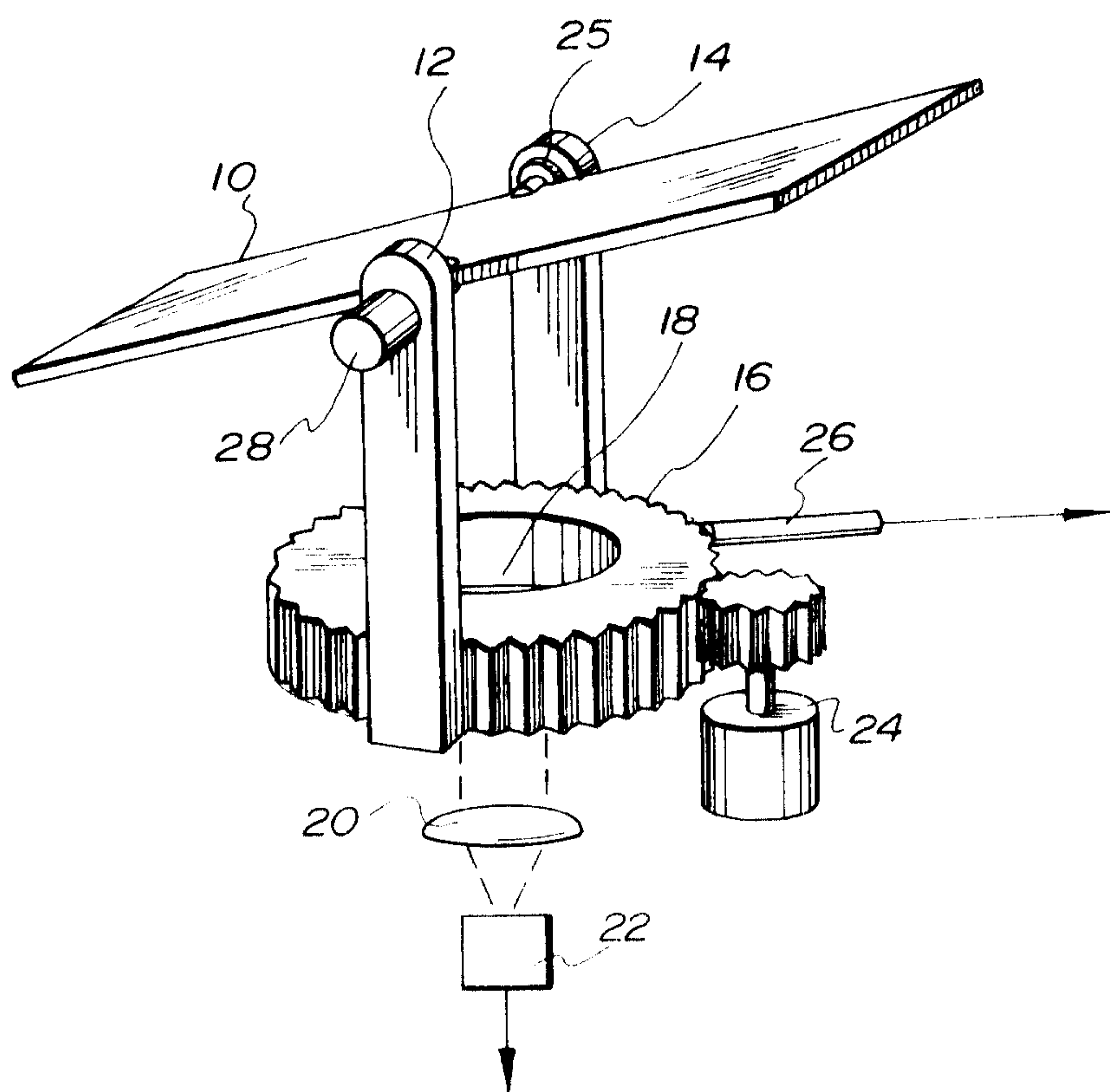


FIG. 1

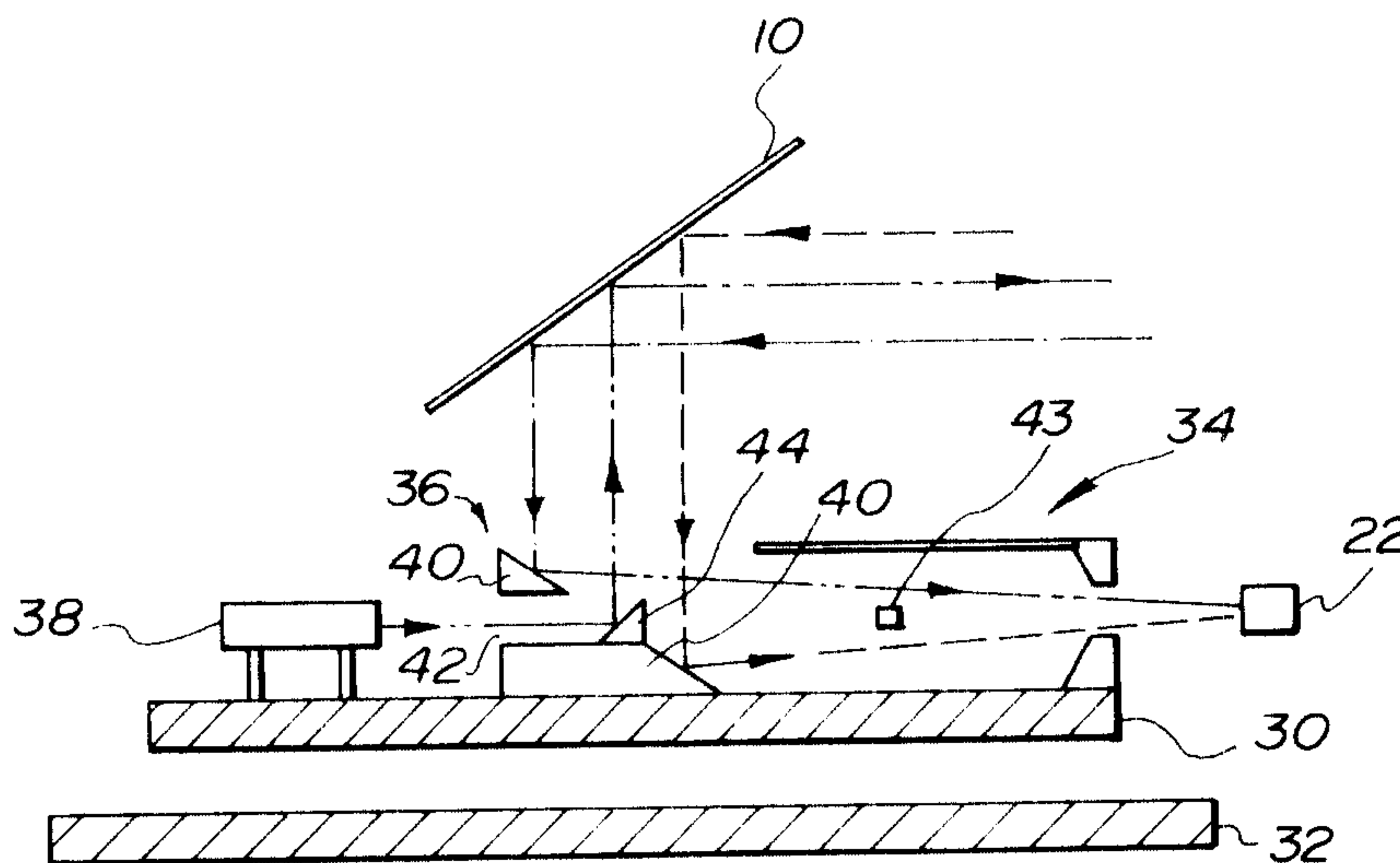


FIG. 2

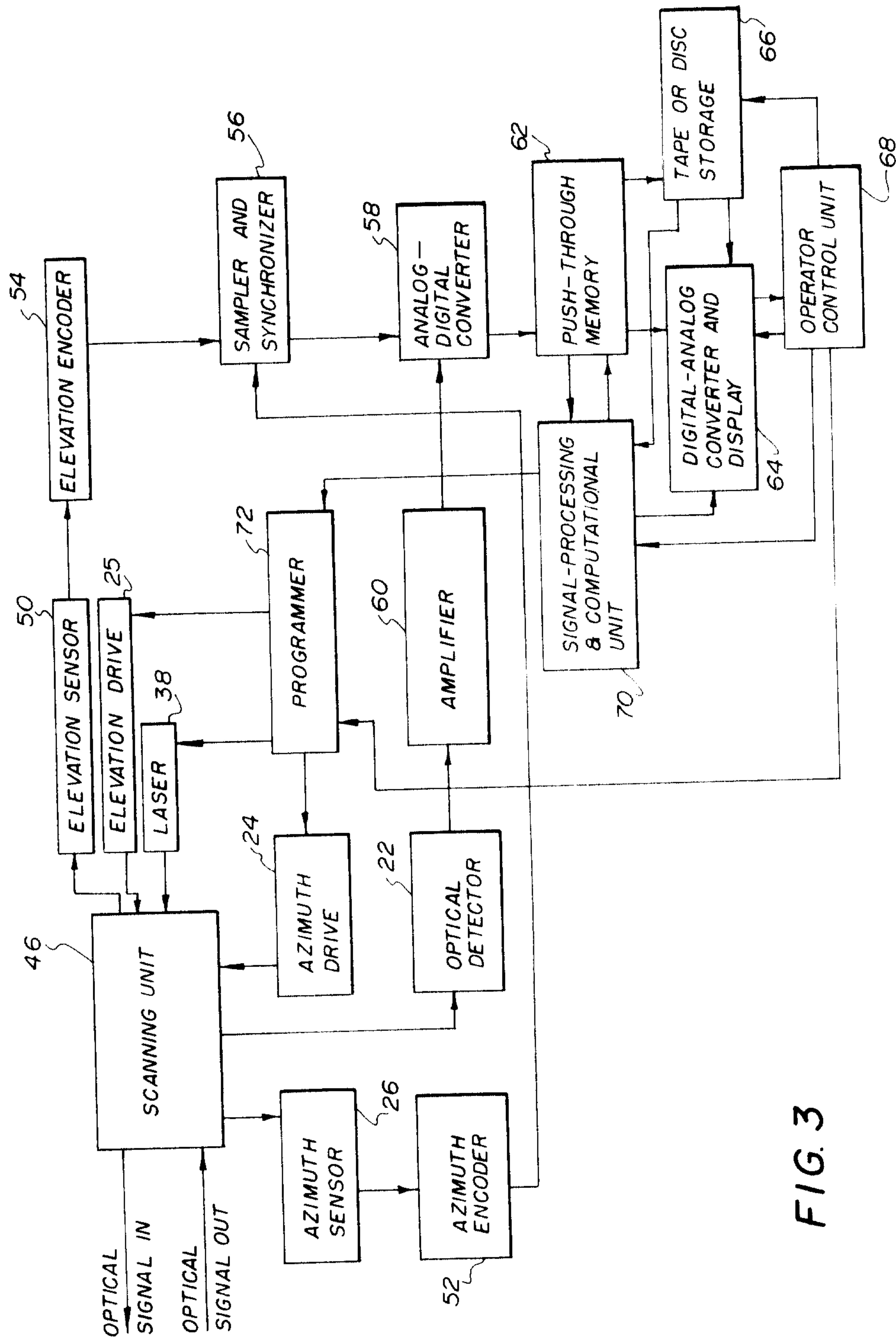


FIG. 3