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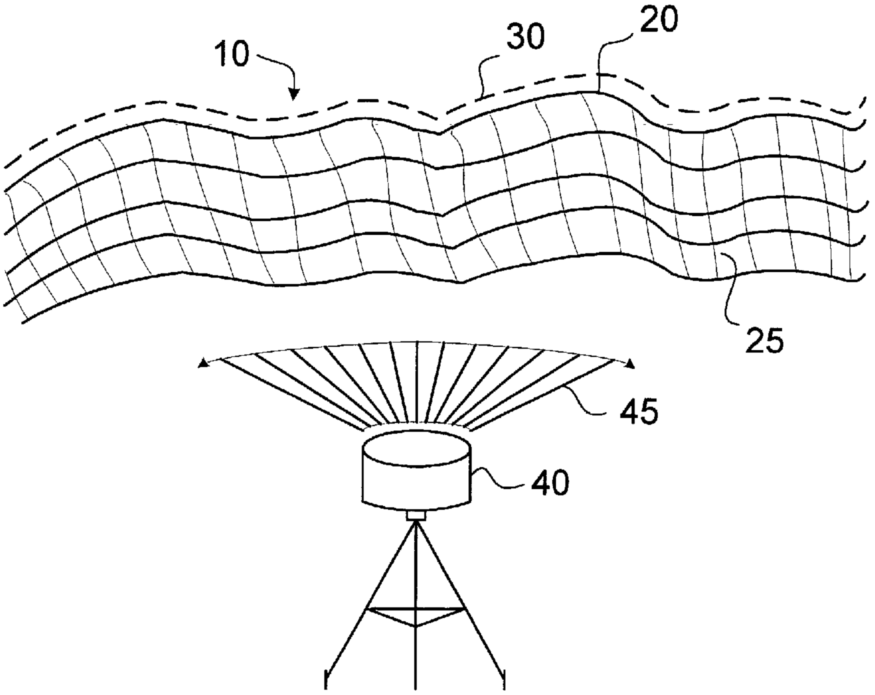
(54) Title: METHOD AND APPARATUS FOR DETECTING A TERRAIN-MASKED HELICOPTER



(57) Abstract: A robot sentry (40) with a scanning laser (45) observes the sky just above the geographic skyline (20) looking for a vertical airflow pattern characteristic of the rotor inflow to a helicopter rotor. The presence of this vertical airflow pattern indicates the probable presence of a reconnaissance helicopter (10) that is using terrain masking.

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Method and Apparatus for Detecting a Terrain-Masked Helicopter

BACKGROUND OF THE INVENTION

Technical Field

This invention relates to the field of surveillance and more specifically to the detection of helicopters that potentially represent a threat.

Background Art

In the field of electronic surveillance, particularly on the modern battle field, helicopters such as the American Apache helicopter, the European Tiger helicopter as well as undoubtedly Russian and other countries' helicopters use mast-mounted sights and terrain masking as a way of acquiring a target while remaining undetected. A typical flight scenario would be for a reconnaissance helicopter to fly very low to the ground while approaching a potential target. The helicopter would then expose a minimal portion of itself, such as a mast-mounted sight, which is analogous to observing a surface ship from a submarine. In the case of the helicopter, terrain between the helicopter and the intended target 'masks' the helicopter's approach.

In the unrelated field of aerodynamics, the operation of a helicopter is fairly well understood. It is an immutable principle of physics that helicopters -- indeed any 'heavier-than-air-craft' -- can only fly because the airfoils, at any given instant, accelerate a mass of air downward that is at least equal to the mass of the aircraft.

On airplanes, the airfoils (called 'wings') are bolted firmly to the fuselage at a fixed angle and the entire craft is accelerated along the runway until sufficient ‘relative airflow’ is generated over the wings that they can deflect a sufficient mass of air to take off. "Lift" is the equal and opposite reaction to that downward deflection of the air.

Helicopter airfoils (called ‘main rotors’) are rotated about a hub with a feathering hinge at the root, which allows the ‘angle of attack’ to be increased or decreased, both ‘cyclically’ and ‘collectively’. Because these rotating wings are capable of generating ‘relative airflow’ solely due to the speed of rotation, it is not necessary for helicopters to have forward speed in order to fly.

But whether we talk about ‘rotary-wing’ or ‘fixed-wing’ aircraft, the greater the forward speed with which the aircraft flies through the air, the greater the volume of air per unit of time that the lifting airfoils will act upon. The greater the mass of air deflected, the less vertical acceleration must be imparted to that air mass in order to provide the ‘lift’ necessary to fly. For example, a crop-spraying airplane flying over a field at only one or two meters above the vegetation will barely rustle the leaves.

On the other hand, slow flying aircraft interact with a smaller volume of air per unit of time and therefore it is necessary to accelerate that air to a greater downward velocity in order to sustain lift. This is the case with a hovering helicopter -particularly a helicopter hovering well clear of the ground -- where there is invariably a column of descending air beneath the craft. Hovering a helicopter ‘out-of-ground-effect’ requires more power than is required for forward flight or hover ‘in-ground-effect’ and is akin to trying to swim up a waterfall.

Referring to FIG. 1, the vertical velocity of the column of air, also known as the ‘rotor intake’ region **15**, above a hovering or slow moving helicopter **10** depends upon several factors including surface wind, main rotor radius, and ‘disc loading’ (that is -- the weight of the helicopter divided by the ‘swept’ area of the rotor disc). The mass of air entering the rotor intake region is necessarily equal to the mass of air exiting the rotor ‘down wash’ region **16** from the helicopter **10**, where helicopter rotor down wash is a fairly well understood phenomenon. Larger helicopters not only have greater mass, but they generally have a higher ‘disc loading’ when compared to smaller helicopters. This is because other design influences limit the practical main rotor radius on large helicopters.

We have discovered a means of protecting a potential target by detecting helicopters that are using terrain masking to approach the target. Our invention uses the aerodynamic principles of helicopter flight to detect these helicopters before they have observed the target. Advantageously, our invention reveals the position of the helicopter to the potential target before the helicopter is aware that it has been detected. This invention addresses a long-felt need by ground troops for protection from approaching low flying helicopters.

SUMMARY OF THE INVENTION

A robot sentry with a scanning laser observes the sky just above the geographic skyline looking for a vertical airflow pattern characteristic of the rotor inflow to a helicopter rotor. The presence of this vertical airflow pattern indicates the probable presence of a reconnaissance helicopter that is using terrain masking. The robot sentry can be set up to survey the surrounding terrain, using for example a video camera to detect the contrast difference between a darker terrain and lighter sky. The robot sentry can automatically establish an ‘observation line’ by laser ranging to the geographic skyline or an operator can set the observation line based on local terrain features should as can be determined from a topographic map.

The helicopter is detected by drawing an imaginary line in space, aiming very short duration and small diameter laser pulses at various points along that line, detecting return signals from individual aerosol particles on that line, and correlating an area of vertically descending particles with the area of a helicopter rotor. Once the helicopter is detected, personnel in the area are alerted to the potential threat.

BRIEF DESCRIPTION OF DRAWINGS

Brief Description of the Several Views of the Drawing

A more complete appreciation of this invention, and many of the attendant advantages thereof, will be readily apparent as the same becomes better understood by reference to the following detailed description when considered in conjunction with the accompanying drawings, wherein:

FIG. 1 illustrates the airflow around a hovering or slow flying helicopter as taught in the prior art;

FIG. 2 illustrates a robot sentry monitoring an observation line located just above a geographic skyline, in accordance with one illustrative embodiment of my invention; and

FIG. 3 depicts the positions of the robot sentry, geographic skyline, and observation line as shown in FIG. 1, as they would be seen on a topographical map.

FIG. 4 depicts the angular relationship of positions of the robot sentry, and observation line as shown in FIG. 1, with respect to an individual laser beam.

FIG. 5 illustrates a functional block diagram of the robot sentry according to one illustrative embodiment of our invention.

FIG. 6 is a flow chart showing the method steps performed by the robot sentry in detecting a helicopter.

FIGS. 7 and 8 illustrate specific details of the procedure of FIG. 6, in accordance with the present invention.

FIG. 9 illustrates an 'edge-detected' video image of the geographic skyline shown in FIG. 2.

FIG. 10 illustrates the geometric relationship between the vertical moving column of air and the individual laser pulses, where this geometric relationship is used within the method steps of FIG. 6.

DETAILED DESCRIPTION OF THE INVENTION

Mode(s) for Carrying Out the Invention

Referring to FIG. 2, which shows one embodiment of our invention, a robot sentry **40** is scanning just above the surrounding terrain **25**. The scanning process consists of transmitting beams **45** of laser pulses and receiving back scatter returns. These back scatter returns result when the laser pulses reflect from individual aerosol particles contained in the air. In order to detect the individual aerosol particles, the laser pulses are both very narrow in diameter, such as 2 microns, and very short in duration, such as < 10 nanoseconds. The laser beams **45** are scanned along an observation line **30** above the geographic skyline **20** below which may be flying a helicopter.

Referring next to FIG. 3, the observation line **30** is depicted on a topographical map **50**. The observation line **30** is located a varying radial distance **35**, that varies with azimuth angle, from the robot sentry **40**. The radial (r) distance **35** from each individual point on the observation line **30** is determined by the underlying terrain **25**, where the distance (r), for example, is the distance from the robot sentry **40** to the nearest available terrain suitable for masking a helicopter **10**. In some embodiments of our invention, the observation line will not fully surround the robot sentry **40**, but will instead only cover an angular sector, such as an anticipated attack direction. In other embodiments of our invention, there are concentric observation lines **30**, such as would be used in mountain foothill terrain.

Referring next to FIG. 4 as well as the preceding FIGs., the robot sentry **40** detects the presence of a helicopter **10** by detecting a vertical column of air at the observation line **30**. The characteristics of this vertical column of air are that it has a diameter equal to the diameter of the rotor intake region, for example 30 feet (10 meters) and the air in the vertical column is moving downward at a relatively high vertical velocity, for example 50 fps (15 m/s). The diameter of the rotor intake region **15** is approximately the same as the helicopter **10** rotor diameter (R).

The air velocity (V) along the propagation direction of an individual laser beam **46** can be determined by a Doppler shift in the laser beam frequency. The laser return can be measured at a specific distance, such as the radial distance **35** to the observation line **30** by setting a ‘range gate’ on the laser receiver. The vertical speed component of the air velocity is given by the following equation.

$$V_V = V * \sin(\theta);$$

where V is the velocity along the propagation direction of the individual laser beam **46**, V_V is the corresponding vertical velocity component, and **θ** is the elevation angle between the individual laser beam **46** and the local horizontal reference **55**.

A relatively large number of laser 'shots' may be required to detect a vertical column of air, substantially equal vertical wind velocities, over a horizontal distance that is equal to the rotor diameter (R) of the helicopter **10**.

Referring next to FIG. 5, a functional block diagram of the robot sentry **40** is shown. The robot sentry includes a laser transmitter **61**, laser receiver **62**, scanner **63** and processor **65**. In one embodiment, the laser scanner **63** includes galvanometer driven horizontal and vertical scanning mirrors **67**, similar to those that may be known in the art of laser printers.

The laser transmitter **61** produces the individual laser pulses **46** described previously. The laser pulses **46** are directed to the scanner **63** by a mirror **68** and a prism **69**. Each individual laser pulse **46** advantageously has certain characteristics that make it more suitable for detecting the velocities of airborne aerosol particles. These characteristics include, for example, pulse amplitude, pulse length and pulse modulation such as a frequency modulated (FM) 'chirp.

The laser receiver **62** receives the back scatter laser returns **47** from individual aerosol particles through the scanner **63** and the prism **69** and demodulates them. The laser receiver **62** advantageously provides certain functions that make it more suitable for detecting the velocities of airborne aerosol particles at specific predetermined ranges from the robot sentry **40**, such as the varying range of the observation line previously described. These functions can include; for example, a selectable (time) range gate and FM demodulation for detecting Doppler frequency shift of the individual back scatter laser returns **47**.

Referring now to both FIGs. 4 and 5, the processor **65** first determines **(step 81)** the location of an observation line **30**, where the observation line can be expressed in the radial format of elevation angle versus azimuth direction with respect to the robot sentry **40**.

Referring now to FIG. 7 and describing a first embodiment of our invention, embodiment, a video camera **64** included in the robot sentry **40** is used to capture a terrain video image **(step 811)**. The video image is processed using 'edge detection' techniques **(step 812)**, whereby the geographic skyline **20** is represented by a series of elevation versus azimuth points. As an example, FIG. 9 shows an edge-detected video image of the terrain shown in FIG. 2. Referring to both FIGs. 2 and 9, the sky typically will be considerably brighter during the daytime hours than surrounding terrain **25**. A geographic skyline **20** is established based on luminance values and contrast ratios, using one of several edge-detection algorithms that may be available in the art of image processing.

In an alternate embodiment of our robot sentry, the processor **65** issues elevation versus azimuth commands **71** to the scanner **63** and uses the laser receiver **62** to detect brightness values directly, in a manner similar to that of a video camera. The resulting brightness data is processed using techniques similar to the edge detection techniques discussed previously.

As previously discussed in conjunction with FIG. 3, the observation line **30** includes a third dimension that can be expressed as range versus azimuth. The observation line **30** is set at a predetermined angular offset, such as for example 0.10°, just above the geographic skyline **20**. The ranges of various points along the geographic skyline **20** are actively measured **(step 813)** by using the laser transmitter **61** in combination with the laser receiver as a laser range finder. The processor

65 issues elevation versus azimuth commands **71** to the scanner **63** that correspond to the geographic skyline **20** that has been previously determined. Typically, the processor **65** will search a predetermined angular offset; for example, ± 2° from the detected edge, looking for a hard laser return from a terrain feature by varying the elevation commands **71** to the scanner **63**. Accordingly, the processor **65** calculates **(step 814)** elevation and range versus azimuth for the observation line **30**.

In other embodiments, a human operator may manually input the range versus azimuth coordinates of the elevation line, based for example on topographical map data. A computer console may be attached to the robot sentry **40** allowing a human operator to calibrate the equipment, by for example manually operated scanning routines for determining the geographic skyline **20**.

Once the observation line **30** has been established, the processor **65** issues commands **71** to the laser scanner **63** to scan **(step 82)** along the observation line. During the scanning step **(step 83)**, the laser transmitter **61** transmits the laser pulses **46**, where the characteristics, such as pulse duration, of each laser pulse **46** are in response to commands issued from the processor **65**. Also during the scanning step, the laser receiver **62** receives the laser back scatter returns **47**, demodulates these returns, and passes 'raw' data back to the processor **65** for further processing. The processor **65** issues commands to the laser receiver **47**, to determine its sensitivity and range gating.

The processor **65** processes **(step 84)** the laser return raw data. As shown in FIG. 8, this processing includes eliminating **(step 841)** extraneous return signals, correlating **(step 842)** the returns to the geographic location of the observation line **30**, and detecting **(step 843)** the Doppler frequency shift of the individual return pulses **47**. The velocity (V) of individual aerosol particles, in the direction of the laser pulse **46** propagation is calculated **(step 844)** in accordance with the geometry of FIG. 10, which is described, below.

Referring back to FIG. 6, the processor **65** compensates **(step 85)** for wind gusts by averaging the aerosol particle velocities over areas that are much larger than that of a helicopter rotor disc. For example, wind gust velocity over a region 100 meters (300 feet) may be averaged out where this is 10 times the area associated with a helicopter rotor disc. In addition, the local wind behavior, due to cliffs, etc, may be observed during the time period when a helicopter is known not to be in the vicinity. This step **(step 85)** establishes the 'background' wind conditions against which variances can be observed.

Next, the processor **65** looks for vertical air velocity variances against the background wind conditions established in **step 85**. The individual vertical air velocities along the observation line **30**, corresponding to the vertical movement of individual aerosol particles, are correlated **(step 86)** to a potential vertical column of air with the area of a helicopter rotor disc, for example 12 meters across. If such a vertical column of air is detected **(step 87)**, the processor issues a threat warning **(step 88)**.

Referring now to FIG. 10, there is shown the geometry associated with detecting the vertical velocity of an individual aerosol particle **100**. The individual aerosol particle **100** is moving downward at a vertical velocity **105** and is impinged upon by laser pulse **46**. Laser pulse **46** travels in a straight-line propagation direction, defining a first coordinate axis **91**. A second coordinate axis **92** is defined perpendicular to the laser pulse **46** propagation direction. The vertical velocity **105** of the aerosol particle **100** can be resolved into this 'propagation direction' coordinate system using basic geometry.

Consider only the vertical velocity of the aerosol particle and disregard horizontal motion, which is compensated for **step 85**. The vertical velocity component along the propagation axis (V) **101** equals the vertical velocity (V_V) of the aerosol particle times the sine of the elevation angle θ. The table below shows some vertical air column speeds with associated elevation angles and the resultant vertical velocity component along the propagation axis (V).

Vertical Velocity (V_V) (meters/ second)	**Elevation Angle (θ)** (degrees)	**Velocity (V)** (meters/ second)
5	2.5	0.22
5	5.0	0.44
5	7.5	0.65
5	10.0	0.87
10	2.5	0.44
10	5.0	0.87
10	7.5	1.31
10	10.0	1.74
10	2.5	0.44
10	5.0	0.87
10	7.5	1.31
10	10.0	1.74
20	2.5	0.87
20	5.0	1.74
20	7.5	2.61
20	10.0	3.47

Table 1 - Vertical Velocity versus Elevation Angle

Accordingly, as described above we have invented both an apparatus and a method to protect ground troops from the threat posed by a potential attacking helicopter that that is using terrain-masking to conceal its presence. Our invention takes advantage of fundamental aerodynamics which dictate that a large mass of air must move essentially in a vertical column through the rotor blades of a helicopter in order for that helicopter to remain airborne. Our invention further takes advantage of modern laser technology that can detect the movement of individual aerosol particles within a moving air stream such as this vertical column of air. Advantageously, ground troops can use our invention for an extra degree of protection from attack helicopters.

Alternate embodiments may be devised without departing from the spirit or the scope of the invention.

* * * * *

CLAIMS

What is claimed is:

1. Apparatus for detecting a helicopter that is masked by the terrain above which it is flying, said apparatus comprising:

(a) a scanner (63) for transmitting and directing an electromagnetic beam along an observation line above terrain where the helicopter may be located;

(b) a receiver (62) for receiving back scatter returns of the beam reflected from aerosol particles in the air; and

(c) a processor (65) connected to said receiver for determining from said back scatter returns the vertical velocity of air movement at the observation line.

2. The apparatus in accordance with claim 1 wherein said scanner transmits a laser beam.

3. The apparatus in accordance with claim 2 wherein said processor determines said vertical velocity in accordance with

$$V_V = V * \sin(\theta),$$

where

(a) V is the velocity along the propagation direction of the laser beam,

(b) V_V is a corresponding vertical velocity component, and

(c) θ is the elevation angle between the laser beam and a local horizontal reference.

4. The apparatus in accordance with claim 3 wherein said processor further correlates a series of determinations of said vertical velocity with the rotor diameter of a helicopter.

5. The apparatus in accordance with claim 1 further comprising a television camera.

6. A method for detecting a helicopter masked by terrain above where the helicopter is flying, said method comprising:

(a) transmitting a beam along an observation line (30) above the terrain (25) where the helicopter may be found;

(b) receiving back scatter returns reflected from aerosol particles in the air along the observation line; and

(c) determining from said back scatter returns the vertical velocity of air movement along the observation line.

7. The method in accordance with claim 5 wherein said beam is a laser beam.

8. The method in accordance with claim 5 wherein said vertical velocity is determined in accordance with

$$V_V = V * \sin(\theta),$$

where

(a) V is the velocity along the propagation direction of the laser beam,

(b) V_V is a corresponding vertical velocity component, and

(c) θ is the elevation angle between the laser beam and a local horizontal reference.

9. The method in accordance with claim 5 further comprising:

selecting only back scatter returns from distances corresponding to said observation line for determination of the vertical velocity of the air movement at said observation line.

10. A method of using a robot sentry to detect a helicopter, having a rotor, that is using terrain masking comprising the steps of:

(a) determining the location of an observation line (30), where this location is selected to be just above a geographic skyline (20) and at a radial distance (35) determined by local terrain (25);

(b) scanning a laser transmitter to point at and trace along said observation line and to transmit a series of laser pulses (45) at said observation line;

(c) receiving back scatter returns from said laser pulses, where such returns are selectively received so that only returns from distances corresponding to said observation line are considered for further processing;

(d) processing said back scatter returns to determine a vertical velocity component of air movement at said observation line; and

(e) correlating a series of vertical velocity measurements with the rotor diameter of the helicopter.

11. The method in accordance with claim 10 wherein said laser pulses have a narrow diameter and a short duration.

12. The method in accordance with claim 10 wherein said laser pulses have a diameter on the order of 2 microns and a duration of less than 10 nanoseconds.

FIG. 1
PRIOR ART

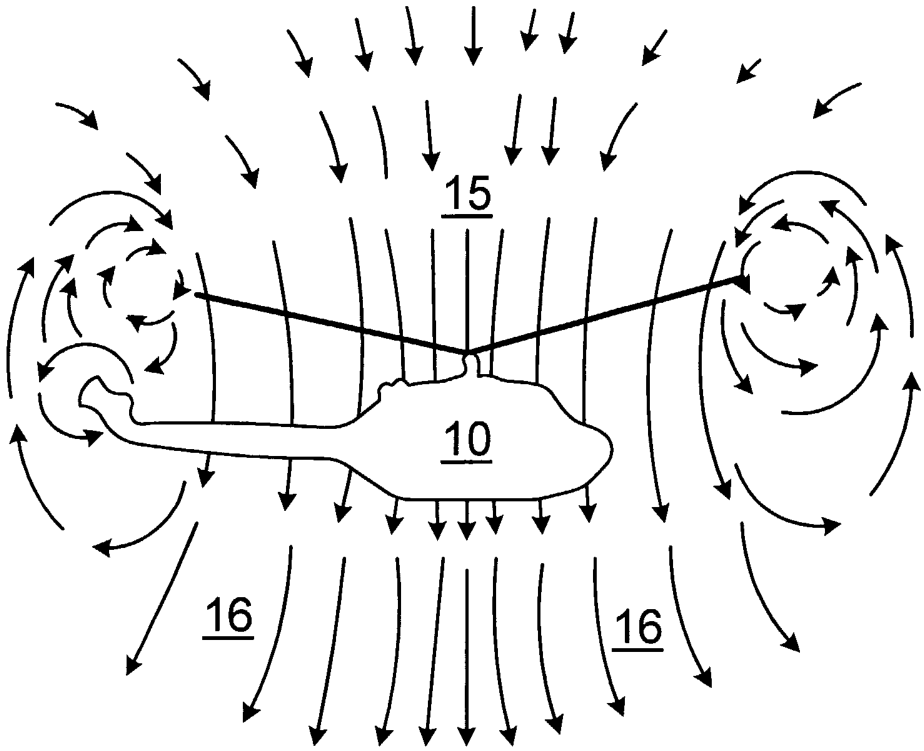

FIG. 2

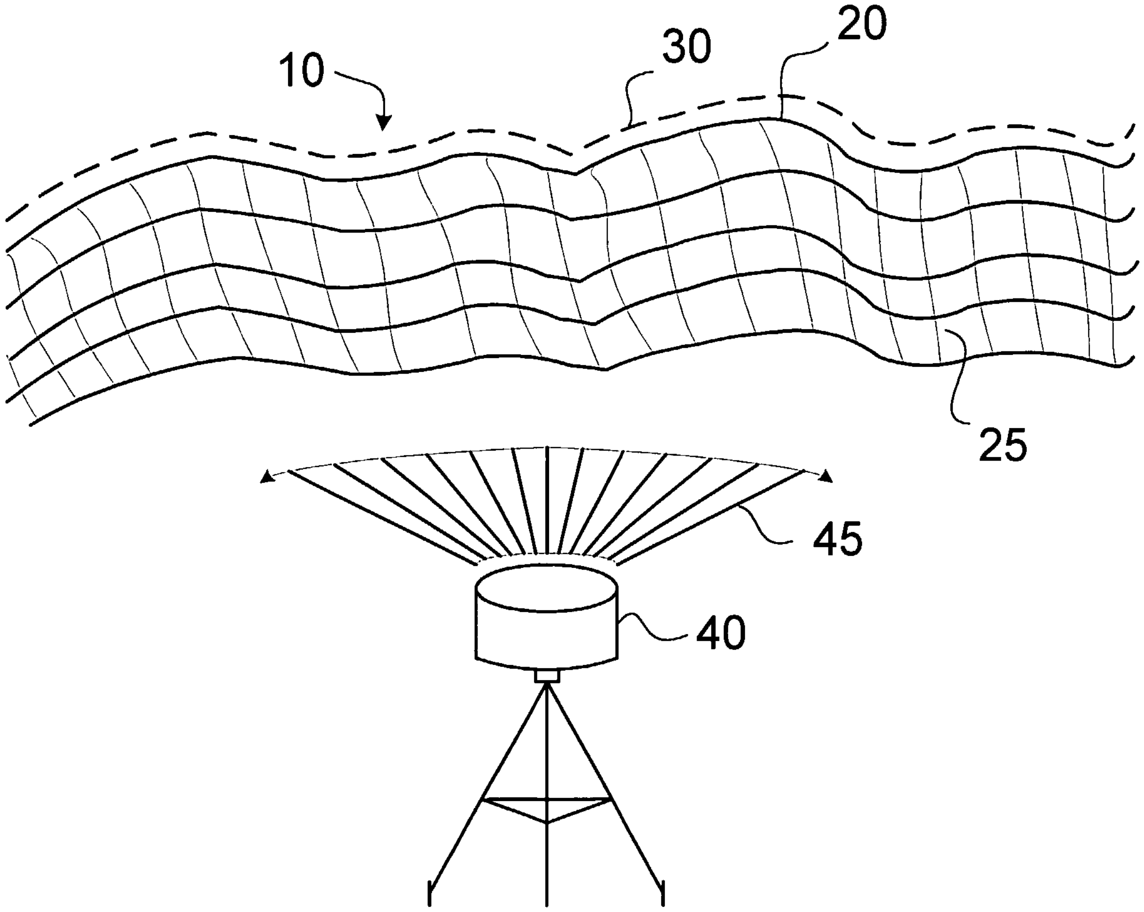

FIG. 3

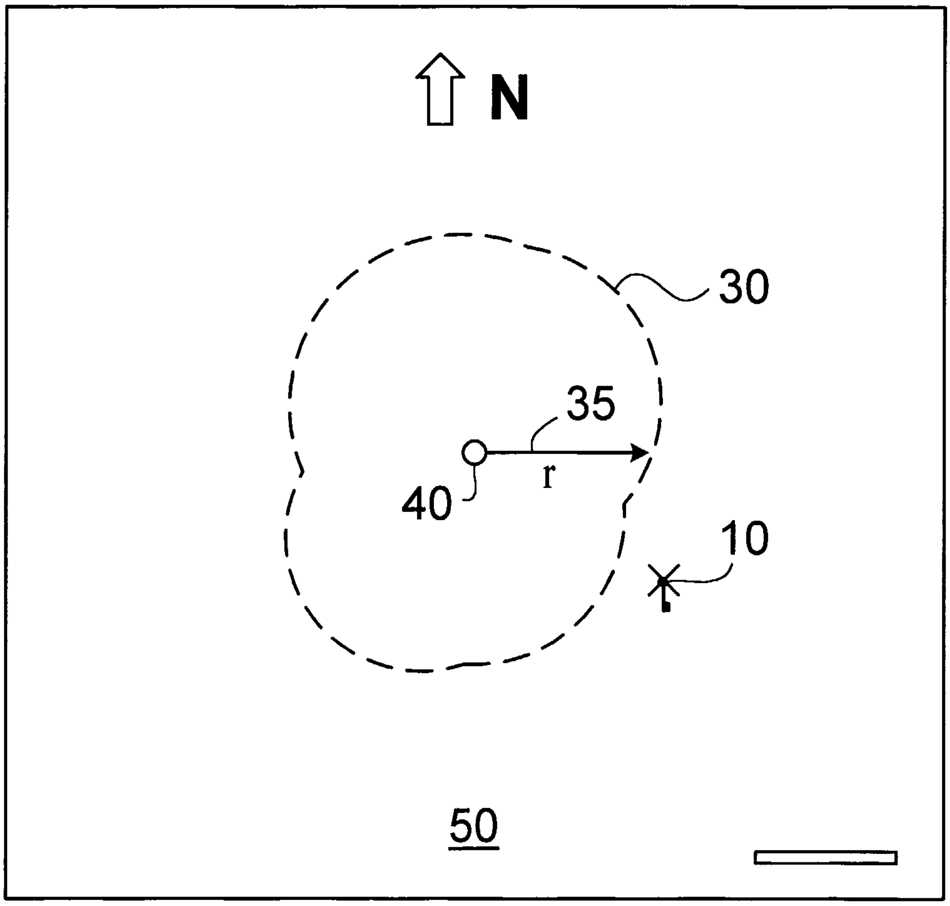

FIG. 4

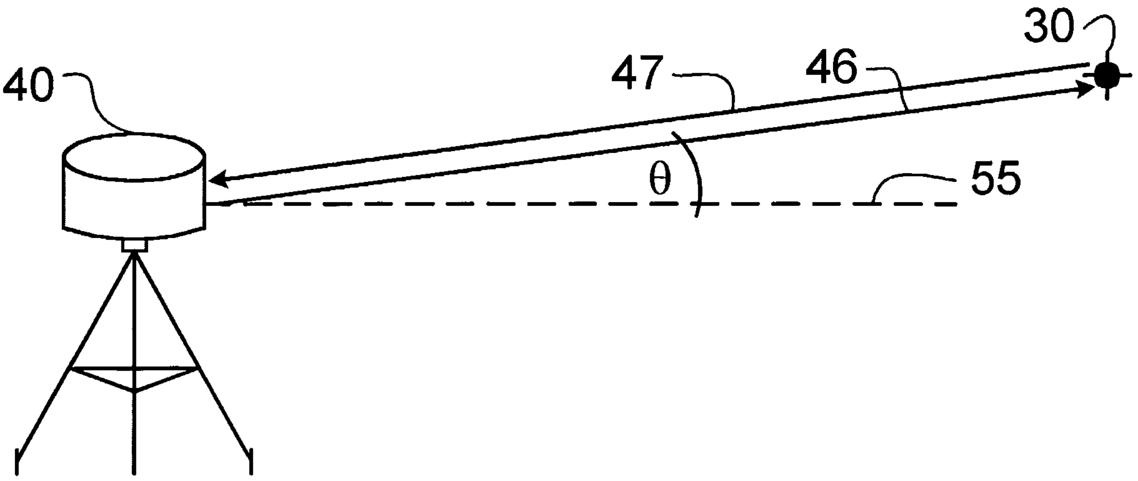

FIG. 5

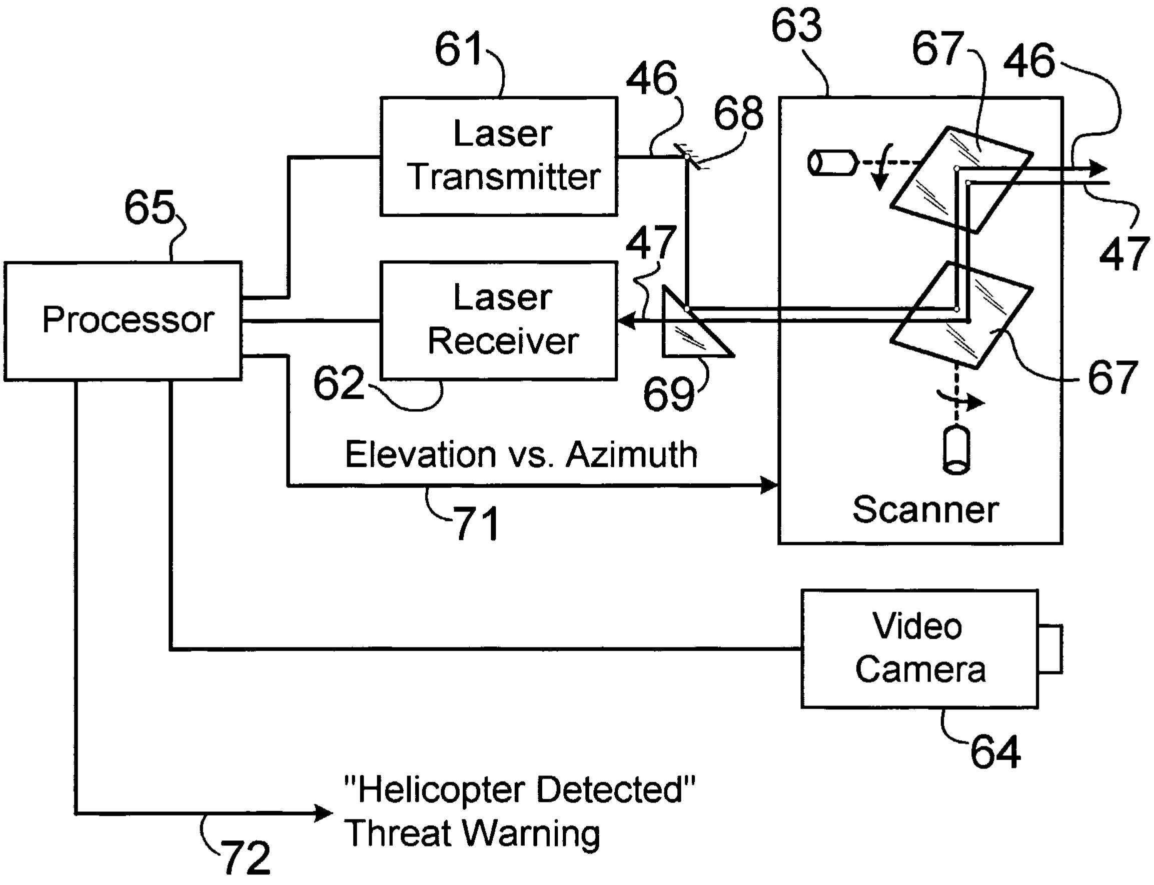
61
Laser Transmitter
46
68
63
67
46
65
Processor
47
Laser Receiver
47
62
69
67
Elevation vs. Azimuth
71
Scanner
Video Camera
64
"Helicopter Detected" Threat Warning
72

FIG. 6

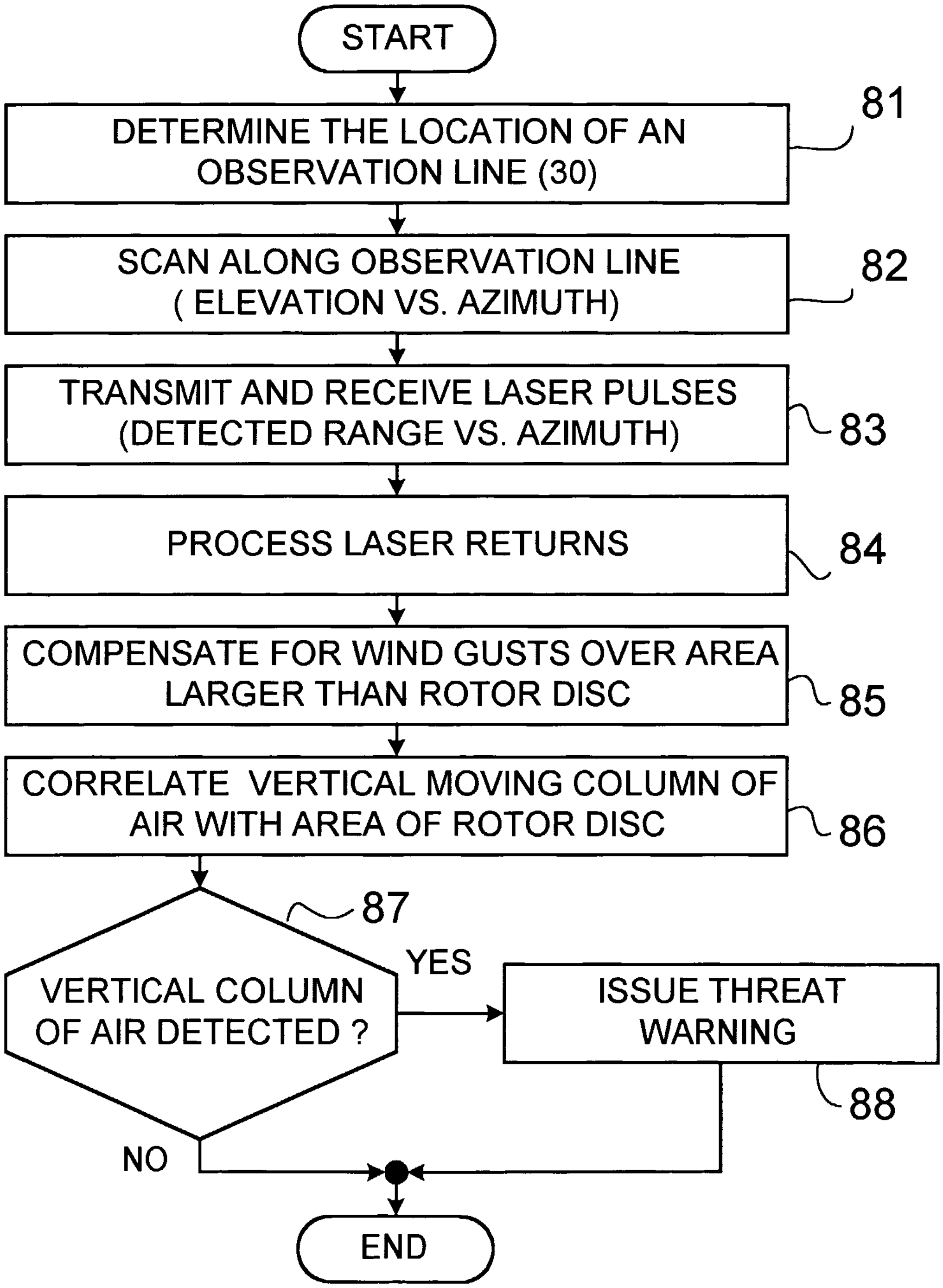
START
DETERMINE THE LOCATION OF AN OBSERVATION LINE (30)
81
SCAN ALONG OBSERVATION LINE (ELEVATION VS. AZIMUTH)
82
TRANSMIT AND RECEIVE LASER PULSES (DETECTED RANGE VS. AZIMUTH)
83
PROCESS LASER RETURNS
84
COMPENSATE FOR WIND GUSTS OVER AREA LARGER THAN ROTOR DISC
85
CORRELATE VERTICAL MOVING COLUMN OF AIR WITH AREA OF ROTOR DISC
86
87
VERTICAL COLUMN OF AIR DETECTED ?
YES
ISSUE THREAT WARNING
88
NO
END

FIG. 7

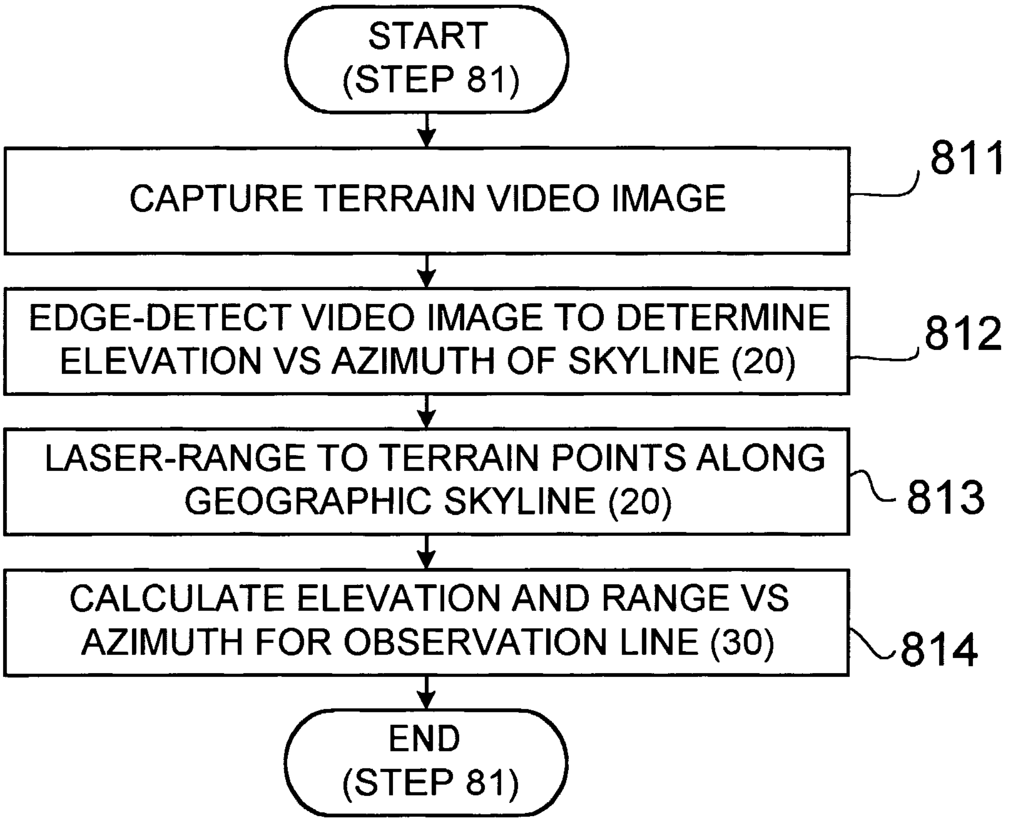
START
(STEP 81)
CAPTURE TERRAIN VIDEO IMAGE
811
EDGE-DETECT VIDEO IMAGE TO DETERMINE ELEVATION VS AZIMUTH OF SKYLINE (20)
812
LASER-RANGE TO TERRAIN POINTS ALONG GEOGRAPHIC SKYLINE (20)
813
CALCULATE ELEVATION AND RANGE VS AZIMUTH FOR OBSERVATION LINE (30)
814
END
(STEP 81)

FIG. 8

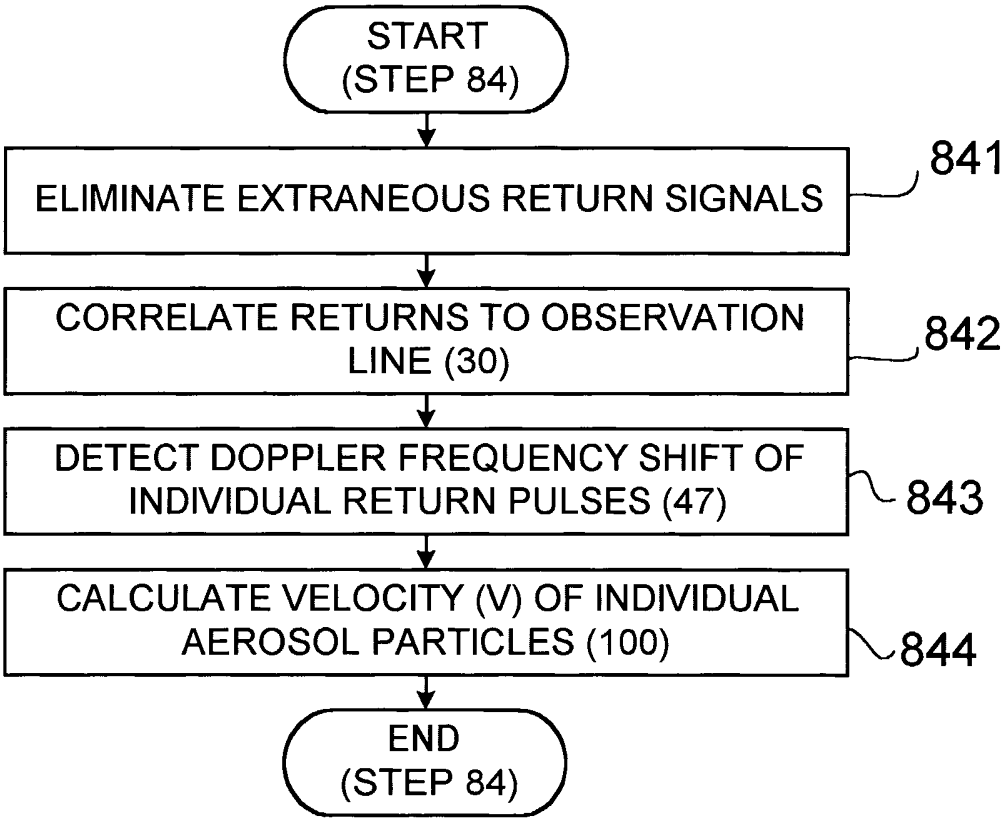
START
(STEP 84)
ELIMINATE EXTRANEOUS RETURN SIGNALS
841
CORRELATE RETURNS TO OBSERVATION LINE (30)
842
DETECT DOPPLER FREQUENCY SHIFT OF INDIVIDUAL RETURN PULSES (47)
843
CALCULATE VELOCITY (V) OF INDIVIDUAL AEROSOL PARTICLES (100)
844
END
(STEP 84)

FIG. 9

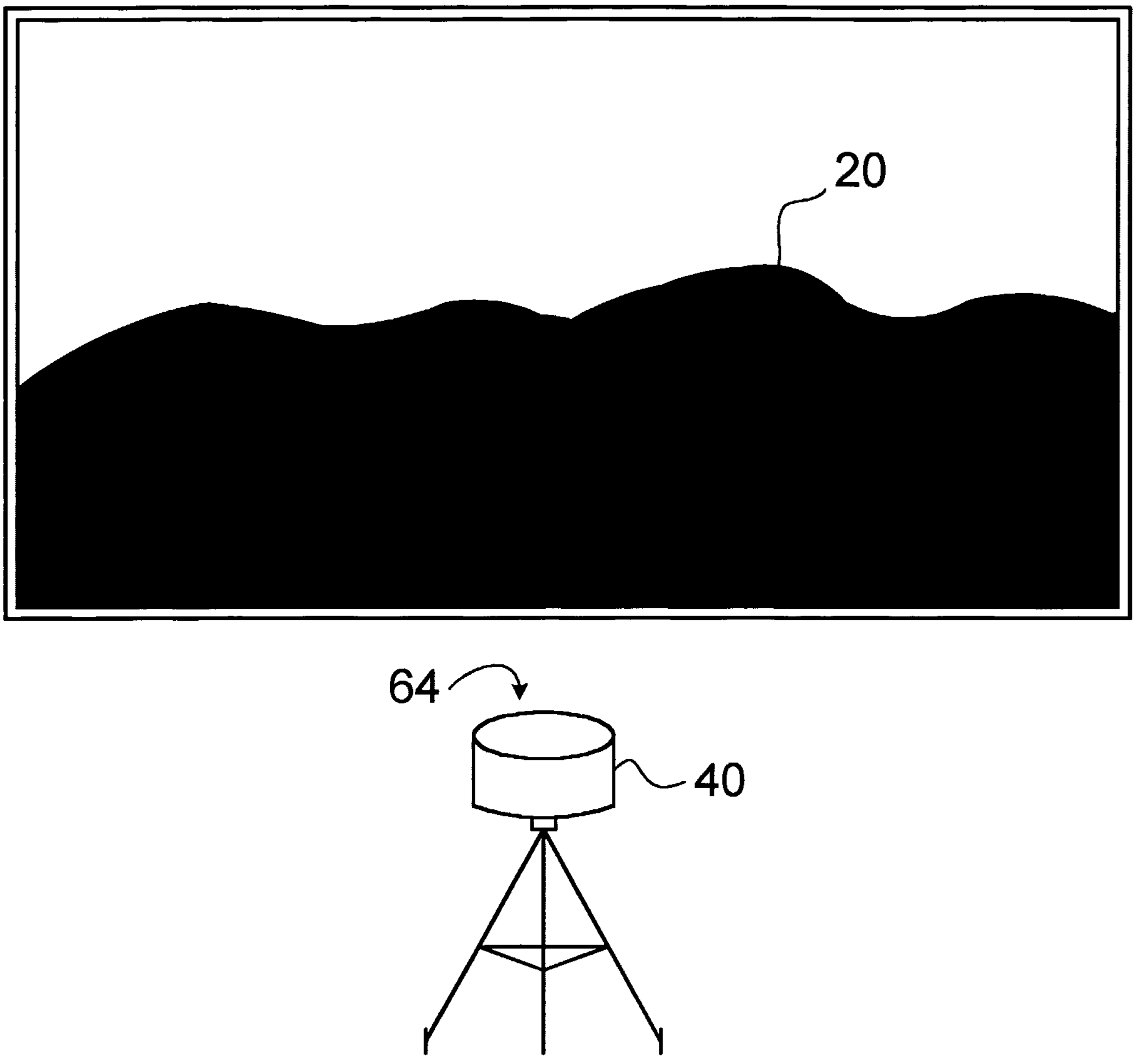

FIG. 10