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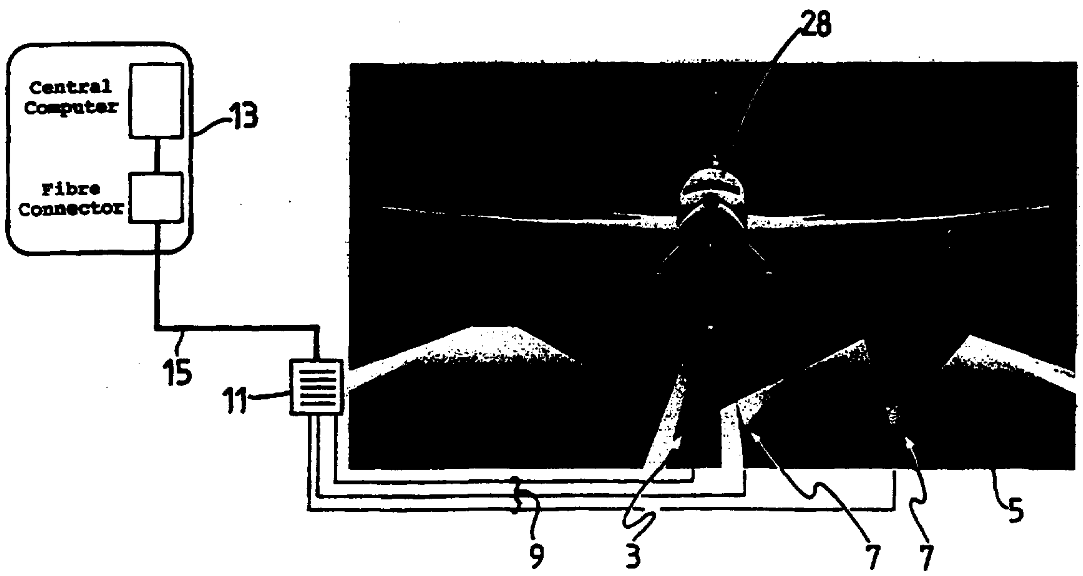

(57) Abstract

An object detection system including passive sensors (3) for receiving electromagnetic radiation from a moving object (28) and generating intensity signals representative of the received radiation, and a processing system for subtracting the intensity signals to obtain a differential signature representative of the position of the moving object. An image acquisition system including at least one camera (7) for acquiring an image of at least part of a moving object, in response to a trigger signal, and an analysis system for processing the image to locate a region in the image including markings identifying the object and processing the region to extract the markings for optical recognition.

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AN AIRCRAFT DETECTION SYSTEM

The present invention relates to an object detection system and, in particular to an aircraft detection system.

The International Civil Aviation Organisation (ICAO) has established regulations which require all civil aircraft to have registration markings beneath the port wing to identify an aircraft. The markings denote the nationality of an aircraft and its registration code granted by the ICAO. In some countries, airline operators do not follow the regulations and the markings appear on an aircraft's fuselage. Owners of aircraft are charged for airport use, but a satisfactory system has not been developed to automatically detect aircraft and then, if necessary, administer a charge to the owner. Microwave signals for detecting an aircraft can interfere with microwave frequencies used for airport communications and, similarly, radar signals can interfere with those used for aircraft guidance systems. A system which can be used to detect an aircraft using unobtrusive passive technology is desired.

In accordance with the present invention there is provided an object detection system including:

passive sensing means for receiving electromagnetic radiation from a moving object and generating intensity signals representative of the received radiation; and

processing means for subtracting said intensity signals to obtain a differential signature representative of the position of said moving object.

The present invention also provides an image acquisition system including:

at least one camera for acquiring an image of at least part of a moving object, in response to a trigger signal, and analysis means for processing said image to locate a region in said image including markings identifying said object and processing said region to extract said markings for a recognition process.

The present invention also provides an object detection method including:

passively sensing electromagnetic radiation received from a moving object;

generating intensity signals representative of the received radiation; and

subtracting said intensity signals to obtain a differential signature representative of the position of said moving object.

The present invention also provides an image acquisition method including:

acquiring an image of at least part of a moving object, in response to a trigger signal, using at least one camera, and

processing said image to locate a region in said image including markings identifying said object and processing said region to extract said markings for a recognition process.

Preferred embodiments of the present invention are hereinafter described, by way of example only, with reference to the accompanying drawings, wherein:

Figure 1 is a block diagram of a preferred embodiment of an aircraft detection system;

Figure 2 is a schematic diagram of a preferred embodiment of the aircraft detection system;

Figure 3 is a block diagram of a connection arrangement for components of the aircraft detection system;

Figure 4 is a more detailed block diagram oi a proximity detector and a tracking system for the aircraft detection system;

Figure 5 is a coordinate system used for the proximity detector;

Figures 6(a) and 6(b) are underneath views of discs of sensors of the tracking system;

Figure 7 is a schematic diagram of an image obtained by the tracking system;

Figures 8 and 9 are images obtained from a first embodiment of the tracking system;

Figure 10 is a graph of a pixel row sum profile for an image obtained by the tracking system;

Figure 11 is a graph of a difference profile obtained by subtracting successive row sum profiles;

Figure 12 is a diagram of a coordinate system for images obtained by the tracking system;

Figure 13 is a diagram of a coordinate system for the aircraft used for geometric correction of the images obtained by the tracking system;

Figure 14 is a diagram of a coordinate system used for predicting a time to generate an acquisition signal;

Figure 15 is a graph of aircraft position in images obtained by the tracking system over successive frames;

Figure 16 is a graph of predicted trigger frame number over successive image frames obtained by the tracking system;

Figure 17 is a schematic diagram of a pyroelectric sensor used in a second embodiment of the tracking system;

Figure 18 is graphs of differential signatures obtained using the second embodiment of the tracking system;

Figures 19 and 20 are images obtained of an aircraft by high resolution cameras of an acquisition system of the aircraft detection system;

Figure 21 is a schematic diagram of an optical sensor system used for exposure control of the acquisition cameras;

Figure 22 is a flow diagram of a preferred character location process executed on image data obtained by the high resolution cameras;

Figure 23 is a diagram of images produced during the character location process; and

Figure 24 is a flow diagram of a character recognition process executed on a binary image of the characters extracted from an image obtained by one of the high resolution cameras.

An aircraft detection system 2, as shown in Figure 1, includes a proximity detector 4, a tracking sensor system 6, an image processing system 8, an image acquisition system 10 and an analysis system 12. A control system 14 can be included to control the image acquisition system 10 on the basis of signals provided by the image processing system 8, and also control an illumination unit 16.

The proximity detector 4 and the tracking sensor system 6 includes sensors 3 which may be placed on or near an aircraft runway 5 to detect the presence of an aircraft 28 using visual or thermal imaging or aural sensing techniques. Also located on or near the runway 5 is at least one high resolution camera 7 of the image acquisition system 10. The sensors 3 and the acquisition camera 7 are connected by data and power lines 9 to an instrument rack 11, as shown in Figure 2, which may be located adjacent or near the runway 5. The instrument rack 11 may alternatively be powered by its own independent supply which may be charged by solar power. The instrument rack 11 includes control circuitry and image processing circuitry which is able to control activation of the sensors 3 and the camera 7 and perform image processing, as required. The instrument rack 11, the data and power lines 9, the sensors 3 and the acquisition camera 7 can be considered to form a runway module which may be located at the end of each runway of an airport. A runway module can be connected back to a central control system 13 using an optical fibre or other data link 15. Images provided by the sensors 3 may be processed and passed to the central system 13 for further processing, and the central system 13 would control triggering of the acquisition cameras 7. Alternatively image processing for determining triggering of the acquisition camera 7 may be performed by each instrument rack 11. The central control system 13 includes the analysis system 12. One method of configuring connection of the instrument racks 11 to the central control system 13 is illustrated in Figure 3. The optical fibre link 15 may include dedicated optical fibres 17 for transmitting video signals to the central control system 13 and other optical fibres 19 dedicated to transmitting data to and receiving data from the central control system 13 using the Ethernet protocol or direct serial data communication. A number of different alternatives can be used for connecting the runway modules to the central control system 13. For example, the runway modules and the control system 13 may be connected as a Wide Area Network (WAN) using Asynchronous Transfer Mode (ATM) or Synchronous Digital Hierarchy (SDH) links. The runway modules and the central control system 13 may also be connected as a Local Area Network (LAN) using a LAN protocol, such as Ethernet. Physical connections may be made between the runway modules and the central control system 13 or alternatively wireless transmission techniques may be used, such as using infrared or microwave signals for communication.

The proximity detector 4 determines when an aircraft is within a predetermined region, and then on detecting the presence of an aircraft activates the tracking sensor system 6. The proximity detector 4, as shown in Figure 4, may include one or more pyroelectric devices 21, judiciously located at an airport, and a signal processing unit 23 and trigger unit 25 connected thereto in order to generate an activation signal to the tracking sensor system 6 when the thermal emission of an approaching aircraft exceeds a predetermined threshold. The proximity detector 4 may use one or more pyroelectric point sensors that detect the infrared radiation emitted from the aircraft 28. A mirror system can be employed with a point sensor 70 to enhance its sensitivity to the motion of the aircraft 28. The point sensor 70 may consist of two or more pyroelectric sensors configured in a geometry and with appropriate electrical connections so as to be insensitive to the background infrared radiation and slowly moving objects. With these sensors the rate of motion of the image of the aircraft 28 across the sensor 70 is important. The focal length of the mirror 72 is chosen to optimise the motion of the image across the sensor 70 at the time of detection. As an example, if the aircraft at altitude H with glide slope angle θ_{GS} moves with velocity V and passes overhead at time t_0, as shown in Figure 5, then the position h of the image of the aircraft 28 on the sensor 70 is

$$h = f\left(\frac{H}{V(t_o - t)} + \tan\theta_{GS}\right) \qquad (1)$$

where f is the focal length of a cylindrical mirror.

If the rate of motion of the image *dh/dt* is required to have a known value, then the focal length of the mirror 72 should be chosen to satisfy

$$f = v\frac{(t_o - t)^2}{H}\frac{dh}{dt} \qquad \textbf{(2)}$$

where $t_0 - t$ is the time difference between the time t_0 at which the aircraft is overhead and the time t at which it is to be detected. Alternatively, the proximity detector 4 may include different angled point sensors to determine when an aircraft enters the monitored region and is about to land or take-off. In response to the activation signal, the tracking sensor system 6 exposes the sensor 3 to track the aircraft. Use of the proximity detector 4 allows the sensor 3 to be sealed in a housing when not in use and protected from damaging environmental conditions, such as hailstorms and blizzards or fuel. The sensor 3 is only exposed to the environment for a short duration whilst an aircraft is in the vicinity of the sensor 3. If the tracking system 6 is used in conditions where the sensor 3 can be permanently exposed to the environment or the sensor 3 can resist the operating conditions, then the proximity detector 4 may not be required. The activation signal generated by the proximity detector 4 can also be used to cause the instrument rack 11 and the central control system 13 to adjust the bandwidth allocated on the link 15 so as to provide an adequate data transfer rate for transmission of video signals from the runway module to the central system 13. If the bandwidth is fixed at an acceptable rate or the system 2 only uses local area network communications and only requires a reduced bandwidth, then again the proximity detector 4 may not be required.

The tracking sensor system 6 includes one or more tracking or detection cameras 3 which obtain images of an aircraft as it approaches or leaves a runway. From a simple image of the aircraft, aspect ratios, such as the ratio of the wingspan to the fuselage length can be obtained. The tracking camera 3 used is a thermal camera which monitors thermal radiation received in the 10 to 14 μm wavelength range and is not dependent on lighting conditions for satisfactory operation. Use of the thermal cameras is also advantageous as distribution of temperatures over the observed surfaces of an aircraft can be obtained, together with signatures of engine exhaust emissions and features in the fuselage or engines. The tracking camera 3 can obtain an instantaneous two-dimensional image I_n using all of the sensors in a CCD array of the camera, or alternatively one row of the array perpendicular to the direction of motion of the aircraft can be used to obtain a linear image at each scan and the linear image is then used to build up a two-dimensional image I_n for subsequent processing.

To allow operation of the tracking and acquisition cameras 3 and 7 in rain, a rotating disc system is employed. The use of a rotating disc for removing water drops from windows is used on marine vessels. A reflective or transparent disc is rotated at high speed in front of the window that is to be kept clear. Water droplets falling on the disk experience a large shear force related to the rotation velocity. The shear force is sufficient to atomise the water drop, thereby removing it from the surface of the disc. A transparent disc of approximate diameter 200 mm is mounted to an electric motor and rotated to a frequency of 60 Hz. A camera with a 4.8 mm focal length lens was placed below a glass window which in turn was beneath the rotating disc. The results of inserting the rotating disc are illustrated in Figure 6(a), which shows the surface of a camera housing without the rotating disc, and in Figure 6(b), which shows the surface of a camera housing with the rotating disc activated and in rain conditions.

The image processing system 8 processes the digital images provided by the tracking sensor system 6 so as to extract in real-time information concerning the features and movement of the aircraft. The images provided to the image processing system, depending on the tracking cameras employed, provide an underneath view of the aircraft, as shown in Figure 7. The tips of the wings or wingspan points 18 of the aircraft are tracked by the image processor system 8 to determine when the image acquisition system 10 should be activated so as to obtain the best image of the registration markings on the port wing 20 of the aircraft. The image processing system 8 generates an acquisition signal using a trigger logic circuit 39 to trigger the camera of the image acquisition system 10. The image processing system 8 also determines and stores data concerning the wingspan 22 of the aircraft and other details concerning the size, shape and ICAO category (A to G) of the aircraft. The image processing system 8 classifies the aircraft on the basis of the size which can be used subsequently when determining the registration markings on the port wing 20. The data obtained can also be used for evaluation of the aircraft during landing and/or take-off.

Alternatively a pyroelectric sensor 27 can be used with a signal processing wing detection unit 29 to provide a tracking system 1 which also generates the acquisition signal using the trigger logic circuit 39, as shown in Figure 4 and described later.

Detecting moving aircraft in the field of view of the sensor 3 or 27 is based on forming a profile or signature of the aircraft, $P(y,t)$, that depends on a spatial coordinate y and time t. To eliminate features in the field of view that are secondary or slowly moving, a difference profile $\Delta P(y,t)$ is formed. The profile or signature can be differenced in time or in space because these differences are equivalent for moving objects. If the intensity of the light or thermal radiation from the object is not changing then the time derivative of the profile obtained from this radiation is zero. A time derivative of a moving field can be written as a convective derivative involving partial derivatives, which gives the equation

$$\frac{dP(y,t)}{dt} = \frac{\partial P(y,t)}{\partial t} + v\frac{\partial P(y,t)}{\partial y} = 0 \qquad \textbf{(3)}$$

where v is the speed of the object as observed in the profile. After rearranging equation (3), gives

$$\frac{\partial P(y,t)}{\partial t} = -v\frac{\partial P(y,t)}{\partial y} \qquad \textbf{(4)}$$

which shows that the difference in the profile in time is equivalent to the difference in the profile in space. This only holds for moving objects, when $v \neq 0$. Equation (4) also follows from the simple fact that if the profile has a given value $P(y_0,t_0)$ at the coordinate (y_0,t_0), then it will have this same value along the line

$$y = y_0 + v(t - t_0) \qquad \textbf{(5)}$$

To detect and locate a moving feature that forms an extremum in the profile, such as an aircraft wing, the profile can be differenced in space $\Delta_y P(y,t)$. Then an extremum in the profile $P(y,t)$ will correspond to a point where the difference profile $\Delta_y P(y,t)$ crosses zero.

In one method for detecting a feature on the aircraft, a profile $P(y,t)$ is formed and a difference profile $\Delta_t P(y,t)$ is obtained by differencing in time, as described below. According to equation (4) this is equivalent to a profile of a moving object that is differenced in space. Therefore the position y_p of the zero crossing point of $\Delta_t P(y,t)$ at time t is also the position of the zero crossing point of $\Delta_y P(y,t)$ which locates an extremum in $P(y,t)$.

In another method for detecting a feature on the aircraft, the difference between the radiation received by a sensor 27 from two points in space is obtained as a function of time, $\Delta_y S(t)$, as described below. If there are no moving features in the field of view, then the difference is constant. If any object in the field of view is moving, then the position of a point on the object is related to time using equation (5). This allows a profile or signature differenced in space to be constructed

$$\Delta_y P(y(t),t) = \Delta_y S(t) \qquad \textbf{(6)}$$

and, as described above, allows an extremum corresponding to an aircraft wing to be located in the profile from the zero crossing point in the differential signature.

The image acquisition system 10 includes at least one high resolution camera 7 to obtain images of the aircraft when triggered. The images are of sufficient resolution to enable automatic character recognition of the registration code on the port wing 20 or elsewhere. The illumination unit 16 is also triggered simultaneously to provide illumination of the aircraft during adverse lighting conditions, such as at night or during inclement weather.

The acquired images are passed to the analysis system 12 which performs Optical Character Recognition (OCR) on the images to obtain the registration code. The registration code corresponds to aircraft type and therefore the aircraft classification determined by the image processing system 8 can be used to assist to the recognition process, particularly when characters of the code are obscured in an acquired image. The registration code extracted and any other information concerning the aircraft can be then passed to other systems via a network connection 24.

Once signals received from the pyroelectric sensors 21 indicate the aircraft 28 is within the field of view of the sensors 3 of the tracking sensor system 6, the tracking system 1 is activated by the proximity detector 4. The proximity detector 4 is usually the first stage detection system to determine when the aircraft is in the proximity of the more precise tracking system 1. The tracking system 1 includes the tracking sensor system 6 and the image processing system 8 and according to one embodiment the images from the detection cameras 3 of the sensor system 6 are used by the image processing system 8 to provide a trigger for the image acquisition system when some point in the image of the aircraft reaches a predetermined pixel position. One or more detection cameras 3 are placed in appropriate locations near the airport runway such that the aircraft passes within the field of view of the cameras 3. A tracking camera 3 provides a sequence of images, $\{I_n\}$. The image processing system 8 subtracts a background image from each image I_n of the sequence. The background image represents an average of a number of preceding images. This yields an image ΔI_n that contains only those objects that have moved during the time interval between images. The image ΔI_n is thresholded at appropriate values to yield a binary image, i.e. one that contains only two levels of brightness, such that the pixels comprising the edges of the aircraft are clearly distinguishable. The pixels at the extremes of the aircraft in the direction perpendicular to the motion of the aircraft will correspond to the edges 18 of the wings of the aircraft. After further processing, described below, when it is determined the pixels comprising the port edge pass a certain position in the image corresponding to the acquisition point, the acquisition system 10 is triggered, thereby obtaining an image of the registration code beneath the wing 20 of the aircraft.

Imaging the aircraft using thermal infrared wavelengths and detecting the aircraft by its thermal radiation renders the aircraft self-luminous so that it can be imaged both during the day and night primarily without supplementary illumination. Infrared (IR) detectors are classified as either photon detectors (termed cooled sensors herein), or thermal detectors (termed uncooled sensors herein). Photon detectors (photoconductors or photodiodes) produce an electrical response directly as the result of absorbing IR radiation. These detectors are very sensitive, but are subject to noise due to ambient operating temperatures. It is usually necessary to cryogenically cool (80°K) these detectors to maintain high sensitivity. Thermal detectors experience a temperature change when they absorb IR radiation, and an electrical response results from temperature dependence of the material property. Thermal detectors are not generally as sensitive as photon detectors, but perform well at room temperature.

Typically, the cooled sensing devices are formed from Mercury Cadmium Telluride offer far greater sensitivity than uncooled devices, which may be formed from Barium Strontium Titanate. Their Net Equivalent Temperature Difference (NETD) is also superior. However, with the uncooled sensor a chopper can be used to provide temporal modulation of the scene. This permits AC coupling of the output of each pixel to remove the average background. This minimises the dynamic range requirements for the processing electronics and amplifies only the temperature differences. This is an advantage for resolving differences between cloud, the sun, the aircraft and the background. The advantage of differentiation between objects is that it reduced the load on subsequent image processing tasks for segmenting the aircraft from the background and other moving objects such as the clouds.

Both a cooled and uncooled thermal infrared imaging system 6 has been used during day, night and foggy conditions. The system 6 produced consistent images of the aircraft in all these conditions, as shown in Figures 8 and 9. In particular, the sun in the field of view produced no saturation artefacts or flaring in the lens. At night, the entire aircraft was observable, not just the lights.

The image processing system 8 uses a background subtraction method in an attempt to eliminate slowly moving or stationary objects from the image, leaving only the fast moving objects. This is achieved by maintaining a background image that is updated after a certain time interval elapses. The update is an incremental one based on the difference between the current image and the background. The incremental change is such that the background image can adapt to small intensity variations in the scene but takes some time to respond to large variations. The background image is subtracted from the current image, a modulus is taken and a threshold applied. The result is a binary image containing only those differences from the background that exceed the threshold.

One problem with this method is that some slow moving features, such as clouds, still appear in the binary image. The reason for this is that the method does not select on velocity but on a combination of velocity and intensity gradients. If the intensity in the image is represented by $I(x,y,t)$, where x and y represent the position in rows and columns, respectively, and t represents the image frame number (time) and if the variation in the intensity due to ambient conditions is very small then it can be shown that the time variation of the intensity in the image due to a feature moving with velocity v is given by

$$\frac{\partial I(x,y,t)}{\partial t} = -v.\nabla I(x,y,t) \qquad \textbf{(7)}$$

In practice, the time derivative in equation (7) is performed by taking the difference between the intensity at (x,y) at different times. Equation (7) shows that the value of this difference depends on the velocity v of the feature at (x,y) and the intensity gradient. Thus a fast moving feature with low contrast relative to the background is identical to a slow moving feature with a large contrast. This is the situation with slowly moving clouds that often have very bright edges and therefore large intensity gradients there, and are not eliminated by this method. Since features in a binary image have the same intensity gradients, better velocity selection is obtained using the same method but applied to the binary image. In this sense, the background-subtraction method is applied twice, once to the original grey-scale image to produce a binary image as described above, and again to the subsequent binary image, as described below.

The output from the initial image processing hardware is a binary image $B(x,y,t)$ where $B(x,y,t) = 1$ if a feature is located at (x,y) at time t, and $B(x,y,t) = 0$ represents the background. Within this image the fast moving features belong to the aircraft. To deduce the aircraft wing position the two-dimensional binary image can be compressed into one dimension by summing along each pixel row of the binary image,

$$P(y,t) = \int B(x,y,t)\, dx \qquad \textbf{(8)}$$

where the aircraft image moves in the direction of the image columns. This row-sum profile is easily analysed in real time to determine the location of the aircraft. An example of a profile is shown in Figure 10 where the two peaks 30 and 31 of the aircraft profile correspond to the main wings (large peak 30) and the tail wings (smaller peak 31).

In general, there are other features present, such as clouds, that must be identified or filtered from the profile. To do this, differences between profiles from successive frames are taken, which is equivalent to a time derivative of the profile. Letting $A(x,y,t)$ be the aircraft where $A(x,y,t) = 1$ if (x,y) lies within the aircraft and 0 otherwise and letting $C(x,y,t)$ represent clouds or other slowly moving objects, then it can be shown that the time derivative of the profile is given by

$$\begin{aligned}\frac{\partial P(y,t)}{\partial t} &= \int \frac{\partial A(x,y,t)}{\partial t} dx + \int \frac{\partial C(x,y,t)}{\partial t} dx - \int \frac{\partial}{\partial t} [A(x,y,t)C(x,y,t)]dx \\ &= \int \frac{\partial A(x,y,t)}{\partial t} [1 - C(x,y,t)]dx + \varepsilon(C)\end{aligned} \qquad \textbf{(9)}$$

where $\varepsilon(C) \approx 0$ is a small error term due to the small velocity of the clouds. Equation (9) demonstrates an obvious fact that the time derivative of a profile gives information on the changes (such as motion) of feature A only when the changes in A do not overlap features C. In order to obtain the best measure of the location of a feature, the overlap between features must be minimised. This means that $C(x,y,t)$ must cover as small an area as possible. If the clouds are present but do not overlap the aircraft, then apart from a small error term, the time difference between profiles gives the motion of the aircraft. The difference profile corresponding to Figure 10 is shown in Figure 11 where the slow moving clouds have been eliminated. The wing positions occur at the zero-crossing points 33 and 34. Note that the clouds have been removed, apart from small error terms.

The method is implemented using a programmable logic circuit of the image processing system 8 which is programmed to perform the row sums on the binary image and to output these as a set of integers after each video field. When taking the difference between successive profiles the best results were obtained using differences between like fields of the video image, i.e. even-even and odd-odd fields.

The difference profile is analysed to locate valid zero crossing points corresponding to the aircraft wing positions. A valid zero crossing is one in which the difference profile initially rises above a threshold I_T for a minimum distance y_T and falls through zero to below $-I_T$ for a minimum distance y_T. The magnitude of the threshold I_T is chosen to be greater than the error term $\varepsilon(C)$ which is done to discount the affect produced by slow moving features, such as clouds.

In addition, the peak value of the profile, corresponding to the aircraft wing, can be obtained by summing the difference values when they are valid up to the zero crossing point. This method removes the contributions to the peak from the non-overlapping clouds. It can be used as a guide to the wing span of the aircraft.

The changes in position of the aircraft in the row-sum profile are used to determine a velocity for the aircraft that can be used for determining the image acquisition or trigger time, even if the aircraft is not in view. This situation may occur if the aircraft image moves into a region on the sensor that is saturated, or if the trigger point is not in the field of view of the camera 3. However, to obtain a reliable estimate of the velocity, geometric corrections to the aircraft position are required to account for the distortions in the image introduced by the camera lens. These are described below using the coordinate systems (x,y,z) for the image and (X,Y,Z) for the aircraft as shown in Figures 12 and 13, respectively.

For an aircraft at distance Z and at a constant altitude Y_0, the angle from the horizontal to the aircraft in the vertical plane is

$$\tan\theta_y = \frac{Y_0}{Z} \qquad \textbf{(10)}$$

Since Y_0 is approximately constant, a normalised variable $Z_N = Z/Y_0$ can be used. If y_0 is the coordinate of the centre of the images, f is the focal length of the lens and θ_c is the angle of the camera from the horizontal in the vertical plane, then

$$\frac{y_0 - y}{f} = \tan(\theta_y - \theta_c) = \frac{\tan\theta_y - \tan\theta_c}{1 + \tan\theta_y \tan\theta_c} \qquad \textbf{(11)}$$

where the tangent has been expanded using a standard trigonometric identity. Using (10) and (11) an expression for the normalised distance Z_N is obtained

$$Z_N(y) = \frac{1 + \beta(y - y_0)\tan\theta_c}{\tan\theta_c - \beta(y - y_0)} \qquad \textbf{(12)}$$

where $\beta = 1/f$. This equation allows a point in the image at y to be mapped onto a true distance scale, Z_N. Since the aircraft altitude is unknown, the actual distance cannot be determined. Instead, all points in the image profile are scaled to be equivalent to a specific point, y_1, in the profile. This point is chosen to be the trigger line or image acquisition line. The change in the normalised distance $Z_N(y_1)$ at y_1 due to an increment in pixel value Δy_1 is $\Delta Z_N(y_1) = Z_N(y_1 + \Delta y_1) - Z_N(y_1)$. The number of such increments over a distance $Z_N(y_2) - Z_N(y_1)$ is $M = (Z_N(y_2) - Z_N(y_1))/\Delta Z_N(y_1)$. Thus the geometrically corrected pixel position at y_2 is

$$y_{c2} = y_1 + M\Delta y_1 = y_1 + \frac{Z_N(y_2) - Z_N(y_1)}{\Delta Z_N(y_1)} \Delta y_1 \qquad \textbf{(13)}$$

For an aircraft at distance Z and at altitude Y_0, a length X on it in the X direction subtends an angle in the horizontal plane of

$$\tan\theta_x = \frac{X}{\sqrt{Y_0^2 + Z^2}} = \frac{X_N}{\sqrt{1 + Z_N^2}} \qquad \textbf{(14)}$$

where normalised values have been used. If x_0 is the location of the centre of the image and f is the focal length of the lens, then

$$\frac{x - x_0}{f} = \tan\theta_x \qquad \textbf{(15)}$$

Using (12), (14) and (15), the normalised distance X_N can be obtained in terms of x and y

$$X_N = \frac{(x - x_0)}{f}\sqrt{1 + Z_N^2(y)} \qquad \textbf{(16)}$$

As with the y coordinate, the x coordinate is corrected to a value at y_1. Since X_N should be independent of position, then a length $x_2 - x_0$ at y_2 has a geometrically corrected length of

$$\begin{aligned} x_{c2} - x_0 &= (x_2 - x_0)\frac{\sqrt{1 + Z_N^2(y_2)}}{\sqrt{1 + Z_N^2(y_1)}} \\ &= (x_2 - x_0)\frac{\sqrt{1 + \beta^2(y_2 - y_0)^2}}{\sin\theta_c - \beta(y_2 - y_0)\cos\theta_c}\,\frac{\sin\theta_c - \beta(y_1 - y_0)\cos\theta_c}{\sqrt{1 + \beta^2(y_1 - y_0)^2}} \end{aligned} \qquad \textbf{(17)}$$

The parameter $\beta = 1/f$ is chosen so that x and y are measured in terms of pixel numbers. If y_0 is the centre of the camera centre and it is equal to half the total number of pixels, and if θ_{FOV} is the vertical field of view of the camera, then

$$\beta = \frac{\tan(\theta_{FOV}/2)}{y_0} \qquad (18)$$

This relation allows β to be calculated without knowing the lens focal length and the dimensions of the sensor pixels.

The velocity of a feature is expressed in terms of the number of pixels moved between image fields (or frames). Then if the position of the feature in frame n is y_n, the velocity is given by $v_n = y_n - y_{n-1}$. Over N frames, the average velocity is then

$$\langle v \rangle = \frac{1}{N}\sum_{n=1}^{N} v_n = \frac{1}{N}\sum_{n=1}^{N}\left(y_n - y_{n-1}\right) = \frac{1}{N}\left(y_N - y_0\right) \qquad (19)$$

which depends only on the start and finish points of the data. This is sensitive to errors in the first and last values and takes no account of the positions in between. The error in the velocity due to an error δy_N in the value y_N is

$$\varepsilon(\langle v \rangle) = \frac{\delta y_N}{N} \qquad (20)$$

A better method of velocity estimation uses all the position data obtained between these values. A time t is maintained which represents the current frame number. Then the current position is given by

$$y = y_0 - vt \qquad (21)$$

where y_0 is the unknown starting point and v is the unknown velocity. The number n of valid positions y_n measured from the feature are each measured at time t_n. Minimising the mean square error

$$\chi^2 = \frac{1}{N}\sum_{n=1}^{N}\left(y_n - y_0 + vt_n\right)^2 \qquad (22)$$

with respect to v and y_0 gives two equations for the unknown quantities y_0 and v. Solving for v yields

$$v = \frac{\sum_{n=1}^{N} y_n \sum_{n=1}^{N} t_n - N \sum_{n=1}^{N} y_n t_n}{N \sum_{n=1}^{N} t_n^2 - \sum_{n=1}^{N} t_n \sum_{n=1}^{N} t_n} \qquad \textbf{(23)}$$

This solution is more robust in the sense that it takes account of all the motions of the feature, rather than the positions at the beginning and at the end of the observations. If the time is sequential, so that $t_n = n\Delta t$ where $t_n = 1$ is the time interval between image frames, then the error in the velocity due to an error δy_n in the value y_n is

$$\varepsilon(\langle v \rangle) = \frac{\delta y_n}{N}\left\{\frac{6(N + 1 - 2n)}{(N + 1)(N - 1)}\right\} \qquad \textbf{(24)}$$

which, for the same error δy_N in (19), gives a smaller error than (21) for $N > 5$. In general, the error in (24) varies as $1/N^2$ which is less sensitive to uncertainties in position than (19).

If the aircraft is not in view, then the measurement of the velocity v can be used to estimate the trigger time. If y_l is the position of a feature on the aircraft that was last seen at a time t_l, then the position at any time t is estimated from

$$y = y_l - v(t - t_l) \qquad \textbf{(25)}$$

Based on this estimate of position, the aircraft will cross the trigger point located at y_T at a time t_T estimated by

$$t_T = t_l - \frac{y_T - y_l}{v} \qquad \textbf{(26)}$$

An alternative method of processing the images obtained by the camera 3 to determine the aircraft position, which also automatically accounts for geometric corrections, is described below. The method is able to predict the time for triggering the acquisition system 10 based on observations of the position of the aircraft 28.

To describe the location of an aircraft 28 and its position, a set of coordinates are defined such that the $\hat{x}$ axis points vertically upwards, the $\hat{z}$ axis points horizontally along the runway towards the approaching aircraft, and $\hat{y}$ is horizontal and perpendicular to the runway. The image 66 of the aircraft is located in the digitised image by pixel values (x_p, y_p), where x_p is defined to be the vertical pixel value and y_p the horizontal value. The lens on the camera inverts the image so that a light ray from the aircraft strikes the sensor at position $(-x_p, -y_p, 0)$, where the sensor is located at the coordinate origin. Figure 14 shows a ray 68 from an object, such as a point on the aircraft, passing through a lens of a focal length f, and striking the imaging sensor at a point $(-x_p, -y_p)$, where x_p and y_p are the pixel values. The equation locating a point on the ray is given by

$$\boldsymbol{r} = x_p(z/f - 1)\hat{\boldsymbol{x}}_c + y_p(z/f - 1)\hat{\boldsymbol{y}}_c + z\hat{\boldsymbol{z}}_c \tag{27}$$

where z is the horizontal distance along the ray, and the subscript c refers to the camera coordinates. The camera axis $\hat{\boldsymbol{z}}_c$ is collinear with the lens optical axis. It will be assumed that $z/f \gg 1$, which is usually the case.

Assuming the camera is aligned so that $\hat{\boldsymbol{y}}_c = \hat{\boldsymbol{y}}$ is aligned with the runway coordinate, but the camera is tilted from the horizontal by angle θ. Then

$$\begin{aligned} \hat{\boldsymbol{x}}_c &= \hat{\boldsymbol{x}} \cos\theta - \hat{\boldsymbol{z}} \sin\theta \\ \hat{\boldsymbol{z}}_c &= \hat{\boldsymbol{x}} \sin\theta + \hat{\boldsymbol{z}} \cos\theta \end{aligned} \tag{28}$$

and a point on the ray from the aircraft to its image is given by

$$\boldsymbol{r} = z\left[\left(x_p \cos\theta / f + \sin\theta\right) \hat{\boldsymbol{x}} + \left(y_p / f\right) \hat{\boldsymbol{y}} + \left(\cos\theta - x_p \sin\theta / f\right) \hat{\boldsymbol{z}}\right] \tag{29}$$

Letting the aircraft trajectory be given by

$$\boldsymbol{r}(t) = \left(z(t) \tan\theta_{GS} + x_0\right) \hat{\boldsymbol{x}} + y_0\hat{\boldsymbol{y}} + z(t)\hat{\boldsymbol{z}} \tag{30}$$

where $z(t)$ is the horizontal position of the aircraft at time t, θ_{GS} is the glide-slope angle, and the aircraft is at altitude x_0 and has a lateral displacement y_0 at $z(t_0) = 0$. Here, $t = t_0$ is the time at which the image acquisition system 10 is triggered, i.e. when the aircraft is overhead with respect to the cameras 7.

Comparing equations (29) and (30) allows z to be written in terms of $z(t)$ and gives the pixel positions as

$$x_p(t) = f\left(\frac{z(t)\left[\cos\theta \tan\theta_{GS} - \sin\theta\right] + x_0 \cos\theta}{z(t)\left[\sin\theta \tan\theta_{GS} + \cos\theta\right] + x_0 \sin\theta}\right) \qquad \textbf{(31)}$$

and

$$y_p(t) = \frac{fy_0}{z(t)\left[\sin\theta \tan\theta_{GS} + \cos\theta\right] + x_0 \sin\theta} \qquad \textbf{(32)}$$

Since $z_p(t)$ is the vertical coordinate and its value controls the acquisition trigger, the following discussion will be centred on equation (31). The aircraft position is given by

$$z(t) = v(t_0 - t) \qquad \textbf{(33)}$$

where v is the speed of the aircraft along the $\hat{\boldsymbol{z}}$ axis.

The aim is to determine t_0 from a series of values of $z_p(t)$ at t determined from the image of the aircraft. For this purpose, it is useful to rearrange (31) into the following form

$$c - t + ax_p - btx_p = 0 \qquad \textbf{(34)}$$

where

$$a = \frac{vt_0(\tan\theta_{GS} + \cot\theta) + x_0}{fv(1 - \tan\theta_{GS} \cot\theta)} \qquad \textbf{(35)}$$

$$b = \frac{\tan\theta_{GS} + \cot\theta}{f(1 - \tan\theta_{GS} \cot\theta)} \qquad \textbf{(36)}$$

and

$$c = t_0 - \frac{x_T x_0}{fv(1 - \tan\theta_{GS}\cot\theta)} \qquad \textbf{(37)}$$

The pixel value corresponding to the trigger point vertically upwards is $x_T = f\cot\theta$. The trigger time, t_0, can be expressed in terms of the parameters a, b and c

$$t_0 = \frac{c + ax_T}{1 + bx_T} \qquad \textbf{(38)}$$

The parameters a, b and c are unknown since the aircraft glide slope, speed, altitude and the time at which the trigger is to occur are unknown. However, it is possible to estimate these using equation (34) by minimising the chi-square statistic. Essentially, equation (34) is a prediction of the relationship between the measured values x_p and t, based on a simple model of the optical system of the detection camera 3 and the trajectory of the aircraft 28. The parameters a, b and c are to be chosen so as to minimise the error of the model fit to the data, i.e. make equation (34) be as close to zero as possible.

Let x_n be the location of the aircraft in the image, i.e. pixel value, obtained at time t_n. Then the chi-square statistic is

$$\chi^2 = \sum_{n=1}^{N} \left(c - t_n + ax_n - bt_nx_n\right)^2 \qquad \textbf{(39)}$$

for N pairs of data points. The optimum values of the parameters are those that minimise the chi-square statistic, i.e. those that satisfy equation (34).

For convenience, the following symbols are defined

$$X = \sum_{n=1}^{N} x_n, \quad T = \sum_{n=1}^{N} t_n, \quad P = \sum_{n=1}^{N} x_nt_n, \quad Y = \sum_{n=1}^{N} x_n^2,$$
$$= \sum_{n=1}^{N} x_n^2t_n, \quad R = \sum_{n=1}^{N} x_nt_n^2, \quad S = \sum_{n=1}^{N} x_n^2t_n^2. \qquad \textbf{(40)}$$

Then the values of a, b and c that minimise equation (39) are given by

$$a = \frac{(NP - XT)(P^2 - NS) - (NR - PT)(PX - NQ)}{(NY - X^2)(P^2 - NS) + (PX - NQ)^2} \qquad \textbf{(41)}$$

$$b = \frac{(NP - XT)(PX - NQ) + (NR - PT)(NY - X^2)}{(NY - X^2)(P^2 - NS) + (PX - NQ)^2} \qquad \textbf{(42)}$$

and

$$c = \frac{T + bP - aX}{N} \qquad \textbf{(43)}$$

On obtaining a, b and c from equations (41) to (43), then t_0 can be obtained from equation (38).

Using data obtained from video images of an aircraft landing at Melbourne airport, a graph of aircraft image position as a function of image frame number is shown in Figure 15. The data was processed using equations (41) to (43) and (38) to yield the predicted value for the trigger frame number $t_0 = 66$ corresponding to trigger point 70. The predicted point 70 is shown in Figure 16 as a function of frame number. The predicted value is $t_0 = 66 \pm 0.5$ after 34 frames. In this example, the aircraft can be out of the view of the camera 3 for up to 1.4 seconds and the system 2 can still trigger the acquisition camera 7 to within 40 milliseconds of the correct time. For an aircraft travelling at 62.5 m/s, the system 2 captures the aircraft to within 2.5 metres of the required position.

The tracking system 6, 8 may also use an Area-Parameter Accelerator (APA) digital processing unit, as discussed in International Publication No. WO 93/19441, to extract additional information, such as the aspect ratio of the wing span to the fuselage length of the aircraft and the location of the centre of the aircraft.

The tracking system 1 can also be implemented using one or more pyroelectric sensors 27 with a signal processing wing detection unit 29. Each sensor 27 has two adjacent pyroelectric sensing elements 40 and 42, as shown in Figure 17, which are electrically connected so as to cancel identical signals generated by each element. A plate 44 with a slit 46 is placed above the sensing elements 40 and 42 so as to provide the elements 40 and 42 with different fields of view 48 and 50. The fields of view 48 and 50 are significantly narrower than the field of view of a detection camera discussed previously. If aircraft move above the runway in the direction indicated by the arrow 48, the first element 40 has a front field of view 48 and the second element 42 has a rear field of view 50. As an aircraft 28 passes over the sensor 27 the first element 40 detects the thermal radiation of the aircraft before the second element 42, the aircraft 28 will then be momentarily in both fields of view 48 and 50, and then only detectable by the second element 42. An example of the difference signals generated by two sensors 27 is illustrated in Figure 18 where the graph 52 is for a sensor 27 which has a field of view that is directed at 90° to the horizontal and a sensor 27 which is directed at 75° to the horizontal. Graph 54 is an expanded view of the centre of graph 52. The zero crossing points of peaks 56 in the graphs 52 and 54 correspond to the point at which the aircraft 28 passes the sensor 27. Using the known position of the sensor 27 the time at which the aircraft passes, and the speed of the aircraft 28, a time can be determined for generating an acquisition signal to trigger the high resolution acquisition cameras 7. The speed can be determined from movement of the zero crossing points over time, in a similar manner to that described previously.

The image acquisition system 10, as mentioned previously, acquires an image of the aircraft with sufficient resolution for the aircraft registration characters to be obtained using optical character recognition. According to one embodiment of the acquisition system 10, the system 10 includes two high resolution cameras 7 each comprising a lens and a CCD detector array. Respective images obtained by the two cameras 7 are shown in Figures 19 and 20.

The minimum pixel dimension and the focal length of the lens determine the spatial resolution in the image. If the dimension of a pixel is L_p, the focal length f and the altitude of the aircraft is h, then the dimension of a feature $W_{\min}$ on the aircraft that is mapped onto a pixel is

$$W_{\min} = \frac{L_p h}{f} \quad \text{or} \quad f = \frac{L_p h}{W_{\min}} \tag{44}$$

The character recognition process used requires each character stroke to be mapped onto at least four pixels with contrast levels having at least 10% difference from the background. The width of a character stroke in the aircraft registration is regulated by the ICAO. According to the ICAO Report, Annex 7, sections 4.2.1 and 5.3, the character height beneath the port wing must be at least 50 centimetres and the character stroke must be 1/6th the character height. Therefore, to satisfy the character recognition criterion, the dimension of the feature on the aircraft that is mapped onto a pixel should be $W_{\min} = 2$ centimetres, or less. Once the CCD detector is chosen, L_p is fixed and the focal length of the system 10 is determined by the maximum altitude of the aircraft at which the spatial resolution $W_{\min} = 2$ centimetres is required.

The field of view of the system 10 at altitude h is determined by the spatial resolution $W_{\min}$ chosen at altitude $h_{\max}$ and the number of pixels N_{pl} along the length of the CCD,

$$W_{FOV} = \frac{N_{pl} W_{\min} h}{h_{\max}} \tag{45}$$

For $h = h_{\max}$ and $N_{pl} = 1552$ the field of view is $W_{FOV} = 31.04$ metres.

To avoid blurring due to motion of the aircraft, the image moves a distance less than the size of a pixel during the exposure. If the aircraft velocity is v, then the time to move a distance equal to the required spatial resolution $W_{\min}$ is

$$t = \frac{W_{\min}}{v} \tag{46}$$

The maximum aircraft velocity that is likely to be encountered on landing or take-off is v = 160 knots = 82 ms $^{-1}$. With W_{min} = 0.02 m, the exposure time to avoid excessive blurring is t < 240 μs.

The focal length of the lens in the system 10 can be chosen to obtain the required spatial resolution at the maximum altitude. This fixes the field of view. Alternatively, the field of view may be varied by altering the focal length according to the altitude of the aircraft. The range of focal lengths required can be calculated from equation (44).

The aircraft registration, during daylight conditions, is illuminated by sunlight or scattered light reflected from the ground. The aircraft scatters the light that is incident, some of which is captured by the lens of the imaging system. The considerable amount of light reflected from aluminium fuselages of an aircraft can affect the image obtained, and is taken into account. The light power falling onto a pixel of the CCD is given by

$$P_p = L_\lambda \Delta\lambda \Omega_{sun} \frac{R_{gnd} R_A A_p}{8 f\#^2} \qquad \textbf{(47)}$$

where L_λ is the solar spectral radiance, $\Delta\lambda$ is the wavelength bandpass of the entire configuration, Ω_{sun} is the solid angle subtended by the sun, R_{gnd} is the reflectivity of the ground, R_A is the reflectivity of the aircraft, A_p is the area of a pixel in the CCD detector and $f\#$ is the lens f-number.

The solar spectral radiance L_λ varies markedly with wavelength λ. The power falling on a pixel will therefore vary over a large range. This can be limited by restricting the wavelength range $\Delta\lambda$ passing to the sensor and optimally choosing the centre wavelength of this range. The optimum range and centre wavelength are chosen to match the characteristics of the imaging sensor.

In one embodiment, the optimum wavelength range and centre wavelength are chosen in the near infrared waveband, 0.69 to 2.0 microns. This limits the variation in light power on a pixel in the sensor to within the useable limits of the sensor. A KODAK™ KAF-1600L imaging sensor (a monolithic silicon sensor with lateral overflow anti-blooming) was chosen that incorporated a mechanism to accommodate a thousandfold saturation of each pixel, giving a total acceptable range of light powers in each pixel of 10^5. This enables the sensor to produce a useful image of an aircraft when very bright light sources, for example the sun, are in its field of view.

The correct choice of sensor and the correct choice of wavelength range and centre wavelength enables an image to be obtained within a time interval that arrests the motion of the aircraft and that provides an image with sufficient contrast on the aircraft registration to enable digital image processing and recognition of the registration characters.

In choosing the wavelength range and centre wavelength, it was important to avoid dazzling light from the supplementary illumination of the illumination unit 16. The optimum wavelength range was therefore set to between 0.69 μm and 2.0 μm.

The power of sunlight falling onto a pixel directly from the sun is

$$P_{p\text{-}sun} = L_\lambda \Delta\lambda \frac{A_p \pi}{4 f\#^2} \quad \textbf{(48)}$$

The relative light powers from the sun and from the aircraft registration falling onto a single pixel is

$$\frac{P_{p\text{-}sun}}{P_p} = \frac{2\pi}{\Omega_{sun} R_{gnd} R_A} \quad \textbf{(49)}$$

With $\Omega_{sun} = 6.8 \times 10^{-5}$ steradians, $R_{gnd} \approx 0.2$ and $R_A = 1$, the ratio is $P_{p\text{-}sun}/P_p = 4.6 \times 10^5$. This provides an estimate of the relative contrast between the image of the sun and the image of the underneath of the aircraft on a CCD pixel. The CCD sensor and system electronics are chosen to accommodate this range of light powers.

In poor lighting conditions, the aircraft registration requires additional illumination from the illumination unit 16. The light source of the unit 16 needs to be sufficient to illuminate the aircraft at its maximum altitude. If the source is designed to emit light into a solid angle that just covers the field of view of the imaging system then the light power incident onto a pixel of the imaging system 10 due to light emitted from the source and reflected from the aircraft is given by

$$P_p = P_s \frac{R_A}{8A_A} \frac{A_p}{N_{ptot} f\#^2} \tag{50}$$

where A_A is the area on the aircraft imaged onto a pixel of area A_p, P_s is the light power of the source, R_A is the aircraft reflectivity, N_{ptot} is the total number of pixels in the CCD sensor and $f\#$ is the f-number of the lens. The power of the source required to match the daytime reflected illumination is estimated by setting $P_p = 7.3 \times 10^{-11}$ W, $R_A = 1$, $A_p = 81\ \mu m^2$, $N_{ptot} = 1552 \times 1032$, $f\# = 1.8$ and noting that $A_A = W_{min}^2$ where $W_{min} = 0.02$ m. Then $P_s = 1.50 \times 10^4$ W. For a Xenon flash lamp, the flash time is typically $t = 300\ \mu s$ which compares favourably with the exposure time to minimise motion blurring. Then the source must deliver an energy of $E_s = P_s t = 4.5$ J. This is the light energy in a wavelength band $\Delta\lambda = 0.1\ \mu m$. Xenon flash lamps typically have 10% of their light energy within this bandpass centred around $\lambda = 0.8\ \mu m$. Furthermore, the flash lamp may only be 50% efficient. Thus the electrical energy required is approximately 90 J. Flash lamps that deliver energies of 1500 J in 300 μs are readily available. Illumination with such a flash lamp during the day reduces the contrast between the direct sun and the aircraft registration, thereby relaxing the requirement for over-exposure tolerance of the CCD sensor. This result depends on the flash lamp directing all of its energy into the field of view only and that the lens focal length is optimally chosen to image the region of dimension $W_{min} = 0.02$ m onto a single pixel.

In one embodiment, the aperture of the lens on the acquisition camera 7 is automatically adjusted to control the amount of light on the imaging sensor in order to optimise the image quality for digital processing. In the image obtained, the intensity level of the registration characters relative to the underside of the aircraft needs to be maintained to provide good contrast between the two for OCR. The power P_s of the flash 16 is automatically adjusted in accordance with the aperture setting *f#* of the acquisition camera 7 to optimise the image quality and maintain the relative contrast between the registration characters and the underside of the aircraft, in accordance with the relationship expressed in equation (50). For example, during the day the aperture of the lens may be very small and the power of the flash may be increased to provide additional illumination of the underside, whereas during night conditions, the aperture may be fully opened and the power of the flash reduced considerably as additional illumination is not required. As an alternative, or in addition, the electrical gain of the electronic circuits connected to an acquisition camera 7 is adjusted automatically to optimise the image quality.

To appropriately set the camera aperture and/or gain one or more point optical sensors 60, 62, as shown in Figure 21, are used to measure the ambient lighting conditions. The electrical output signals of the sensors 60, 62 are processed by the acquisition system 10 to produce the information required to control the camera aperture and/or gain. Two point sensors 60, 62 sensitive to the same optical spectrum as the acquisition cameras 7 can be used. One sensor 60 receives light from the sky that passes through a diffusing plate 64 onto the sensor 60. The diffusing plate 64 collects light from many different directions and allows it to reach the sensor 60. The second sensor 62 is directed towards the ground to measure the reflected light from the ground.

The high resolution images obtained of the aircraft by the acquisition system 10 are submitted, as described previously, to the analysis system 12 which performs optical character recognition on the images to extract the registration codes of the aircraft.

The analysis system 12 processes the aircraft images obtained by a high resolution camera 7 according to an image processing procedure 100, as shown in

Figure 22, which is divided into two parts 102 and 104. The first part 102 operates on a sub-sampled image 105, as shown in Figure 23, to locate regions that contain features that may be registration characters, whereas the second part 104 executes a similar procedure but is done using the full resolution of the original image and is executed only on the regions identified by the first part 102. The sub-sampled image 105 is the original image with one pixel in four removed in both row and column directions, resulting in a one in sixteen sampling ratio. Use of the sub-sampled image improves processing time sixteen-fold.

The first part 102 receives the sub-sampled image at step 106 and filters the image to remove features which are larger than the expected size of the registration characters (b) at step 108. Step 108 executes a morphological operation of linear closings applied to a set of lines angled between 0 and 180°. The operation passes a kernel or window across the image 105 to extract lines which exceed a predetermined length and are at a predetermined angle. The kernel or window is passed over the image a number of times and each time the predetermined angle is varied. The lines extracted from all of the passes are then subtracted from the image 105 to provide a filtered difference image 109. The filtered difference image 109 is then thresholded or binarised at step 110 to convert it from a grey scale image to a binary scale image 111. This is done by setting to 1 all image values that are greater than a threshold and setting to 0 all other image values. The threshold at a given point in the image is determined from a specified multiple of standard deviations from the mean calculated from the pixel values within a window centred on the given point. The binarised image 111 is then filtered at step 112 to remove all features that have pixel densities in a bounding box that are smaller or larger than the expected pixel density for a bounded registration character. The image 111 is then processed at step 114 to remove all features which are not clustered together like registration characters. Step 114 achieves this by grouping together features that have similar sizes and that are close to one another. Groups of features that are smaller than a specified size are removed from the image to obtain a cleaned image 113. The cleaned image 113 is then used at step 116 to locate regions of interest. Regions of interest are obtained in step 116 from the location and extents of the groups remaining after step 114. Step 116 produces regions of interest which include the registration characters and areas of the regions are bounded above and below, as for the region 115 shown in Figure 23.

The regions of interest obtained by the first part 102 of the procedure 100 are further processed individually using the full resolution of the original image and the second part 104 of the procedure. The second part 104 takes a region of interest 115 from the original image at step 120 and for that region filters out features larger than the expected character sizes at step 122, using the same morphological operation of linear closings applied to a set of lines angled between 0 and 180°, followed by image subtraction, as described above, to obtain image 117. The filtered image 117 is then binarised at step 124 by selecting a filter threshold that is representative of the pixel values at the edges of features. To distinguish the registration characters from the aircraft wing or body the filter threshold needs to be set correctly. A mask image of significant edges in image 117 is created by calculating edge-strengths at each point in image 117 and setting to 1 all points that have edge-strengths greater than a mask threshold and setting to 0 all other points. An edge-strength is determined by taking at each point pixel gradients in two directions, Δx and Δy, and calculating $\sqrt{\Delta x^2 + \Delta y^2}$ to give the edge-strength at that point. The mask threshold at a given point is determined from a specified multiple of standard deviations from the mean calculated from the edge-strengths within a window centred on the given point. The filter threshold for each point in image 117 is then determined from a specified multiple of standard deviations from the mean calculated from the pixel values at all points within a window centred on the given point that correspond to non-zero values in the mask image. The binarised image 118 is then filtered at step 126 to remove features that are smaller than the expected character sizes. Features are clustered together at step 128 that have similar sizes, that are near to one another and that are associated with similar image values in image 117. At step 130 the correctly clustered features that have sizes, orientations and relative positions that deviate too much from the averages for the clusters are filtered out to leave features that form linear chains. Then at step 132, if the number of features remaining in the image produced by step 130 is greater than 3, then a final image is created by rotating image 118 to align the linear chain of features with the image rows and by masking out features not belonging to the linear chain. The final image is passed to a character recognition process 200 to determine whether the features are registration characters and, if so, which characters.

The final image undergoes a standard optical character recognition process 200, as shown in Figure 24, to generate character string data which represents the ICAO characters on the port wing. The process 200 includes receiving the final image at step 202, which is produced by step 132 of the image processing procedure 100, and separating the characters of the image at step 204. The size of the characters are normalised at step 206 and at step 208 correction for the alignment of the characters is made and further normalisation occurs. Character features are extracted at step 210 and an attempt made to classify the features of the characters extracted at step 212. Character rules are applied to the classified features at step 214 so as to produce a binary string representative of the registration characters at step 216.

Although the system 2 has been described above as being one which is particularly suitable for detecting an aircraft, it should be noted that many features of the system can be used for detecting and identifying other moving objects. For example, the embodiments of the tracking system 1 may be used for tracking land vehicles. The system 2 may be employed to acquire images of and identify automobiles at tollway points on a roadway.

Many modifications will be apparent to those skilled in the art without departing from the scope of the present invention as hereinbefore described with reference to the accompanying drawings.

CLAIMS:

1. An object detection system including:

passive sensing means for receiving electromagnetic radiation from a moving object and generating intensity signals representative of the received radiation; and

processing means for subtracting said intensity signals to obtain a differential signature representative of the position of said moving object.

2. An object detection system as claimed in claim 1, wherein said processing means generates an image acquisition signal on the basis of said differential signature.

3. An object detection system as claimed in claim 2, including acquisition means, responsive to said acquisition signal, for acquiring an image of at least part of said moving object; and

analysis means for processing said image to identify said moving object.

4. An object detection system as claimed in claim 3, wherein said analysis system processes said acquired image to extract markings to identify said moving object.

5. An object detection system as claimed in claim 1, 2, 3 or 4, wherein said moving object is an aircraft.

6. An object detection system as claimed in claim 5, wherein said aircraft is in flight.

7. An object detection system as claimed in claim 5, wherein said electromagnetic radiation is thermal radiation.

8. An object detection system as claimed in claim 5, including proximity detecting means for detecting the presence of said aircraft within a predetermined region and, in response thereto, generating an activation signal for said passive sensing means.

9. An object detection system as claimed in claim 1, wherein said passive sensing means includes imaging means for obtaining images of said radiation at successive periods of time, and

said processing means generates respective profiles of pixel values for said images and a difference profile, generated from the difference between successive profiles, which includes said differential signature.

10. An object detection system as claimed in claim 9, wherein said position corresponds to a zero crossing point in said difference profile where said difference profile has risen above a first predetermined threshold for at least a first predetermined distance and then falls to below a second predetermined threshold for a second predetermined distance.

11. An object detection system as claimed in claim 10, wherein said processing means monitors the movement of said position in successive ones of said difference profile and determines the time for generation of an image acquisition signal.

12. An object detection system as claimed in claim 11, wherein said processing means generates a background image from successive images obtained by said imaging means and subtracts said background image from images of said radiation before generating said profiles.

13. An object detection system as claimed in claim 1, wherein said passive sensing means includes pyroelectric sensors with different fields of view and said intensity signals include at least first and second signals representative of the thermal radiation present in said views, respectively, and

said processing means subtracts said first and second signals to obtain a differential signal including said differential signature.

14. An object detection system as claimed in claim 13, wherein said processing means determines a time for generation of an image acquisition signal on the basis of the position of said passive sensing means, the time of generation of said differential signature and the speed of said moving object.

15. An object detection system as claimed in claim 14, wherein said time of generation and said speed are determined from a zero crossing point of said differential signature.

16. An image acquisition system including:

at least one camera for acquiring an image of at least part of a moving object, in response to a trigger signal, and

analysis means for processing said image to locate a region in said image including markings identifying said object and processing said region to extract said markings for a recognition process.

17. An image acquisition system as claimed in claim 16, wherein said camera images received radiation between 0.69 to 2.0 μm.

18. An image acquisition system as claimed in claim 17, wherein said camera has an exposure time of $<$ 240 μs.

19. An image acquisition system as claimed in claim 17, including an infrared flash having its power adjusted on the basis of the aperture setting of said camera.

20. An image acquisition system as claimed in claim 17, including optical sensor means positioned to obtain measurements of ambient direct light and reflected light for the field of view of said camera and adjust settings of said camera on the basis of said measurements.

21. An image acquisition system as claimed in claim 16, wherein said analysis means sub-samples said image, extracts lines exceeding a predetermined length and at predetermined angles, binarises the image, removes features smaller or larger than said markings, removes features not clustered as said markings, and locates said region using the remaining features.

22. An image acquisition system as claimed in claim 21, wherein said analysis means extracts said region from said image and processes said region by removing features larger than expected marking sizes, binarising said region, removing features smaller than expected marking sizes, removing features not clustered as identifying markings, and passing the remaining image for optical recognition if including more than a predetermined number of markings.

23. An image acquisition system as claimed in claim 17, wherein said moving object is an aircraft.

24. An image acquisition system as claimed in claim 23, wherein said aircraft is in flight.

25. An object detection system as claimed in claim 2, including an image acquisition system as claimed in any one of claims 16 to 24, wherein said trigger signal is said image acquisition signal.

26. An object detection method including:

passively sensing electromagnetic radiation received from a moving object;

generating intensity signals representative of the received radiation; and

subtracting said intensity signals to obtain a differential signature representative of the position of said moving object.

27. An object detection method as claimed in claim 26, including generating an image acquisition signal on the basis of said differential signature.

28. An object detection method as claimed in claim 27, including acquiring an image of at least part of said moving object in response to said acquisition signal; and processing said image to identify said moving object.

29. An object detection method as claimed in claim 28, including processing said acquired image to extract markings identifying said moving object.

30. An object detection method as claimed in claim 26, 27, 28 or 29, wherein said moving object is an aircraft.

31. An object detection method as claimed in claim 30, wherein said aircraft is in flight.

32. An object detection method as claimed in claim 30, wherein said electromagnetic radiation is thermal radiation.

33. An object detection method as claimed in claim 30, including detecting the presence of said aircraft within a predetermined region and, in response thereto, generating an activation signal to execute said passive sensing step.

34. An object detection method as claimed in claim 26, wherein said passive sensing includes imaging said radiation at successive periods of time, and

said subtracting includes generating respective profiles of pixel values for images of said radiation and generating a difference profile, from the difference between successive profiles, which includes said differential signature.

35. An object detection method as claimed in claim 34, wherein said position corresponds to a zero crossing point in said difference profile where said difference profile has risen above a first predetermined threshold for at least a first predetermined distance and then falls to below a second predetermined threshold for a second predetermined distance.

36. An object detection method as claimed in claim 35, including monitoring the movement of said position in successive ones of said difference profile and determining the time for generation of an image acquisition signal.

37. An object detection method as claimed in claim 36, wherein said subtracting includes generating a background image from successive images of said radiation imaging means and subtracting said background image from images of said radiation before generating said profiles.

38. An object detection method as claimed in claim 26, wherein said passive sensing includes pyroelectric sensing with different fields of view and said intensity signals include at least first and second signals representative of the thermal radiation present in said views, respectively, and

said subtracting includes subtracting said first and second signals to obtain a differential signal including said differential signature.

39. An object detection method as claimed in claim 38, including determining a time for generation of an image acquisition signal on the basis of the position of passive sensors, the time of generation of said differential signature and the speed of said moving object.

40. An object detection method as claimed in claim 39, wherein said time of generation and speed are determined from a zero crossing point of said differential signature.

41. An image acquisition method including:

acquiring an image of at least part of a moving object, in response to a trigger signal, using at least one camera, and

processing said image to locate a region in said image including markings identifying said object and processing said region to extract said markings for a recognition process.

42. An image acquisition method as claimed in claim 41, wherein said camera images received radiation between 0.69 to 2.0 μm.

43. An image acquisition method as claimed in claim 42, wherein said camera has an exposure time of $<$ 240 μs.

44. An image acquisition method as claimed in claim 42, including adjusting the power of an infrared flash for said camera on the basis of the aperture setting of said camera.

45. An image acquisition method as claimed in claim 42, including obtaining automatic measurements of ambient direct light and reflected light for the field of view of said camera and adjusting settings of said camera on the basis of said measurements.

46. An image acquisition method as claimed in claim 41, wherein said image processing includes sub-sampling said image, extracting lines exceeding a predetermined length and at predetermined angles, binarising the image, removing features smaller or larger than said markings, removing features not clustered as said markings, and locating said region using the remaining features.

47. An image acquisition method as claimed in claim 46, wherein said region processing includes extracting said region from said image, removing features larger than expected marking sizes, binarising said region, removing features with areas smaller or larger than expected marking areas, removing features not clusterec as identifying markings, and passing the remaining image for optical recognition if including more than a predetermined number of markings.

48. An image acquisition method as claimed in claim 42, wherein said moving object is an aircraft.

49. An image acquisition method as claimed in claim 48, wherein said aircraft is in flight.

50. An object detection method as claimed in claim 27, including an image acquisition method as claimed in any one of claims 41 to 49, wherein said trigger signal is said image acquisition signal.

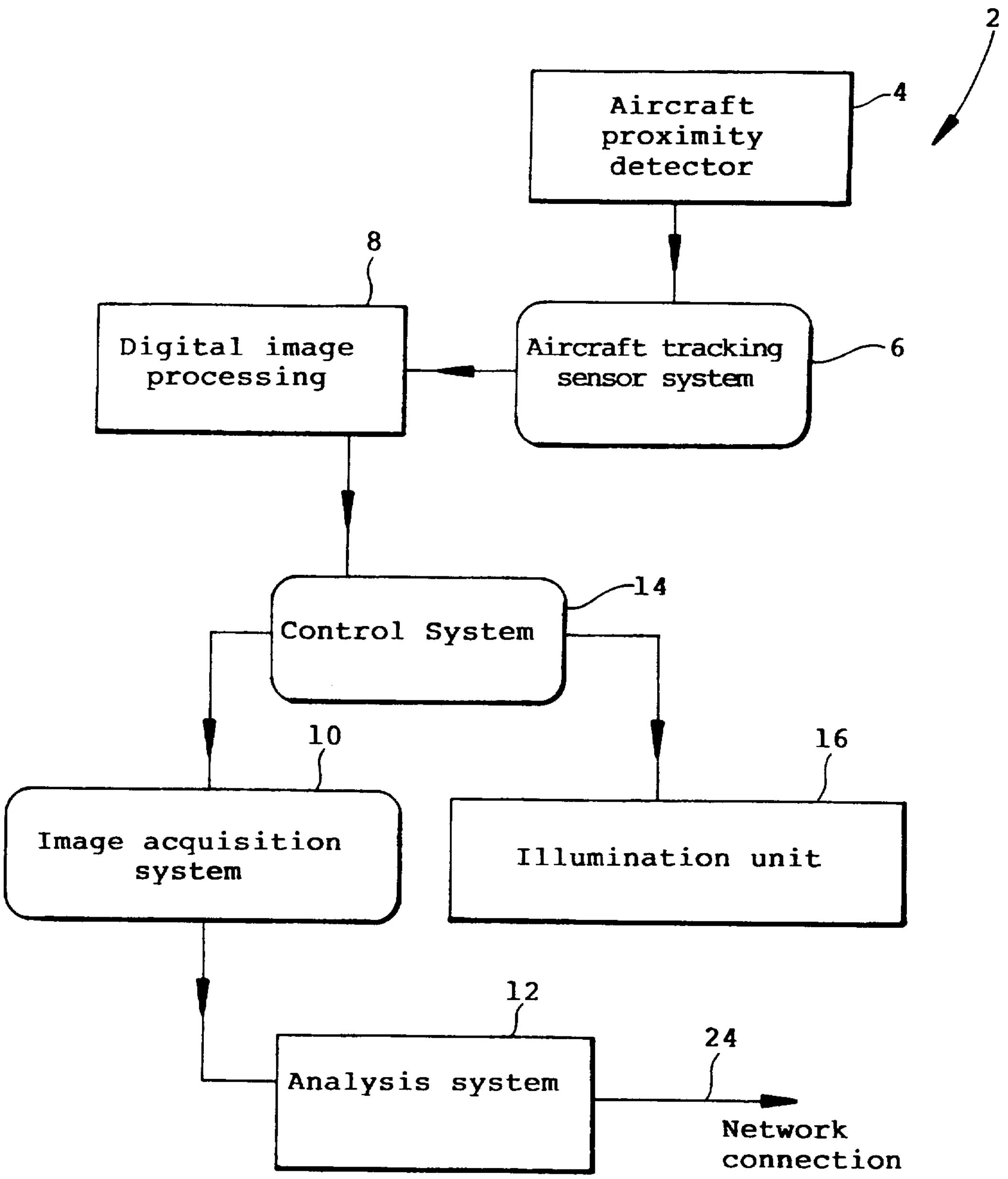

2
Aircraft proximity detector
4
8
Digital image processing
Aircraft tracking sensor system
6
Control System
14
10
16
Image acquisition system
Illumination unit
12
24
Analysis system
Network connection

FIGURE 1

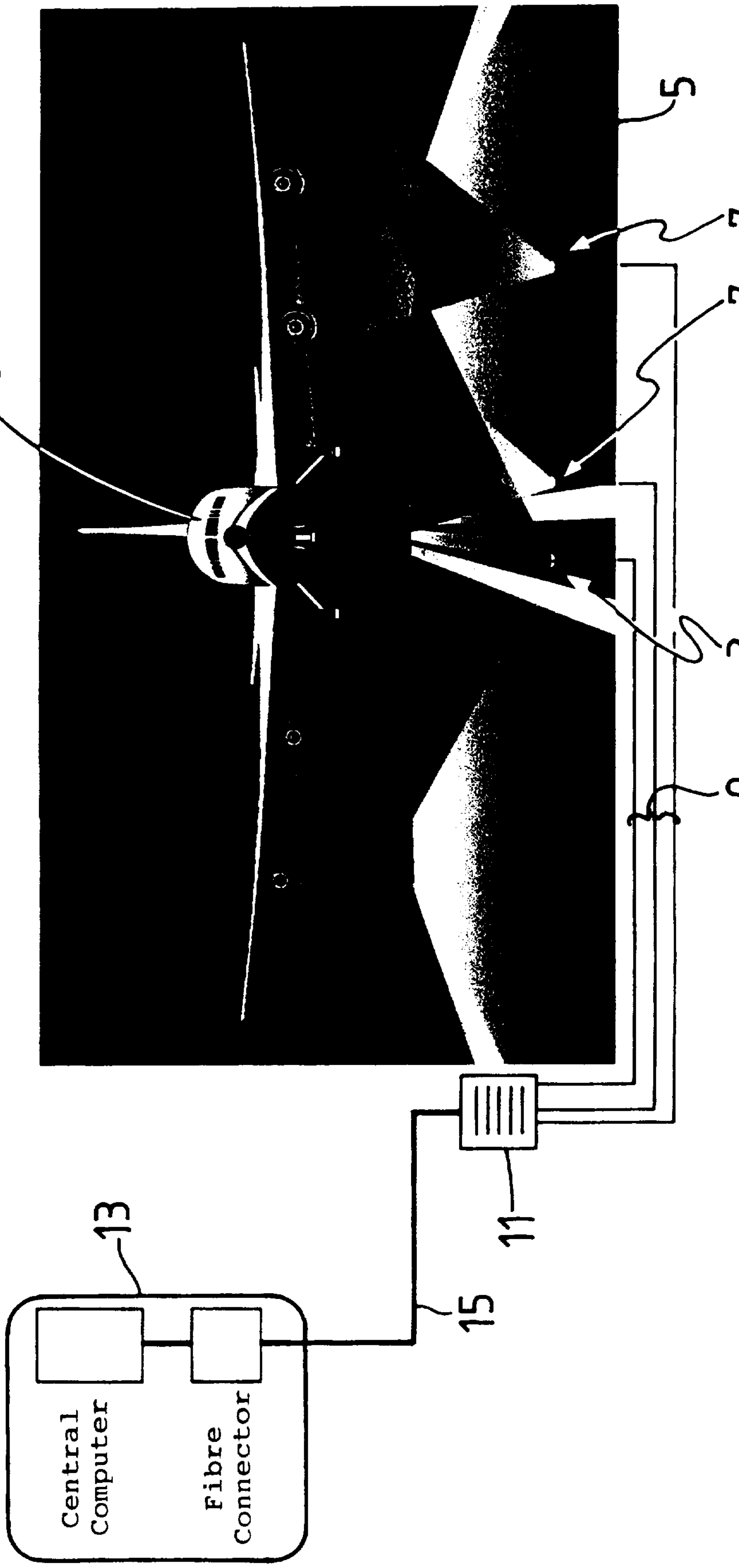


FIGURE 2

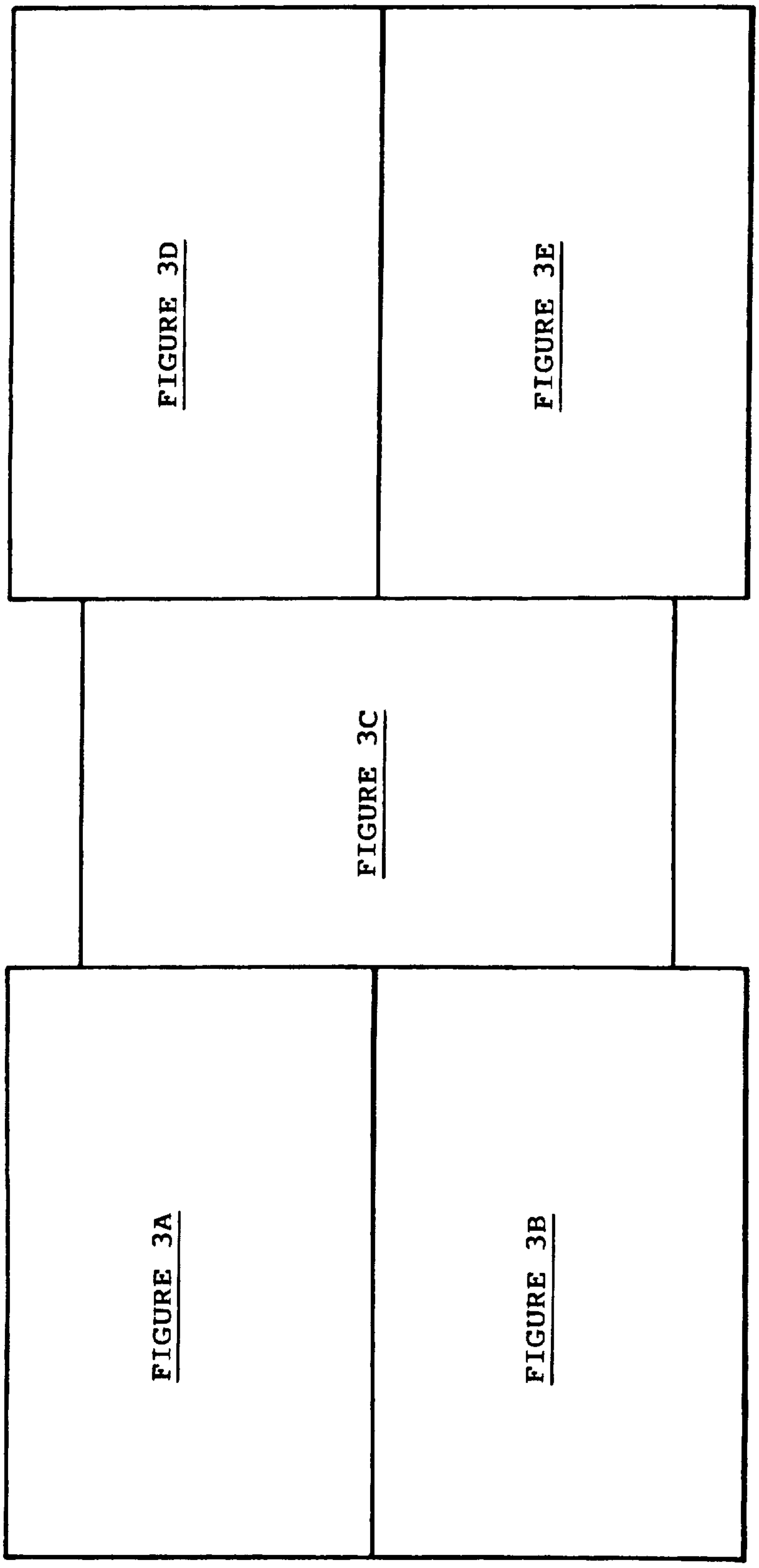


FIGURE 3

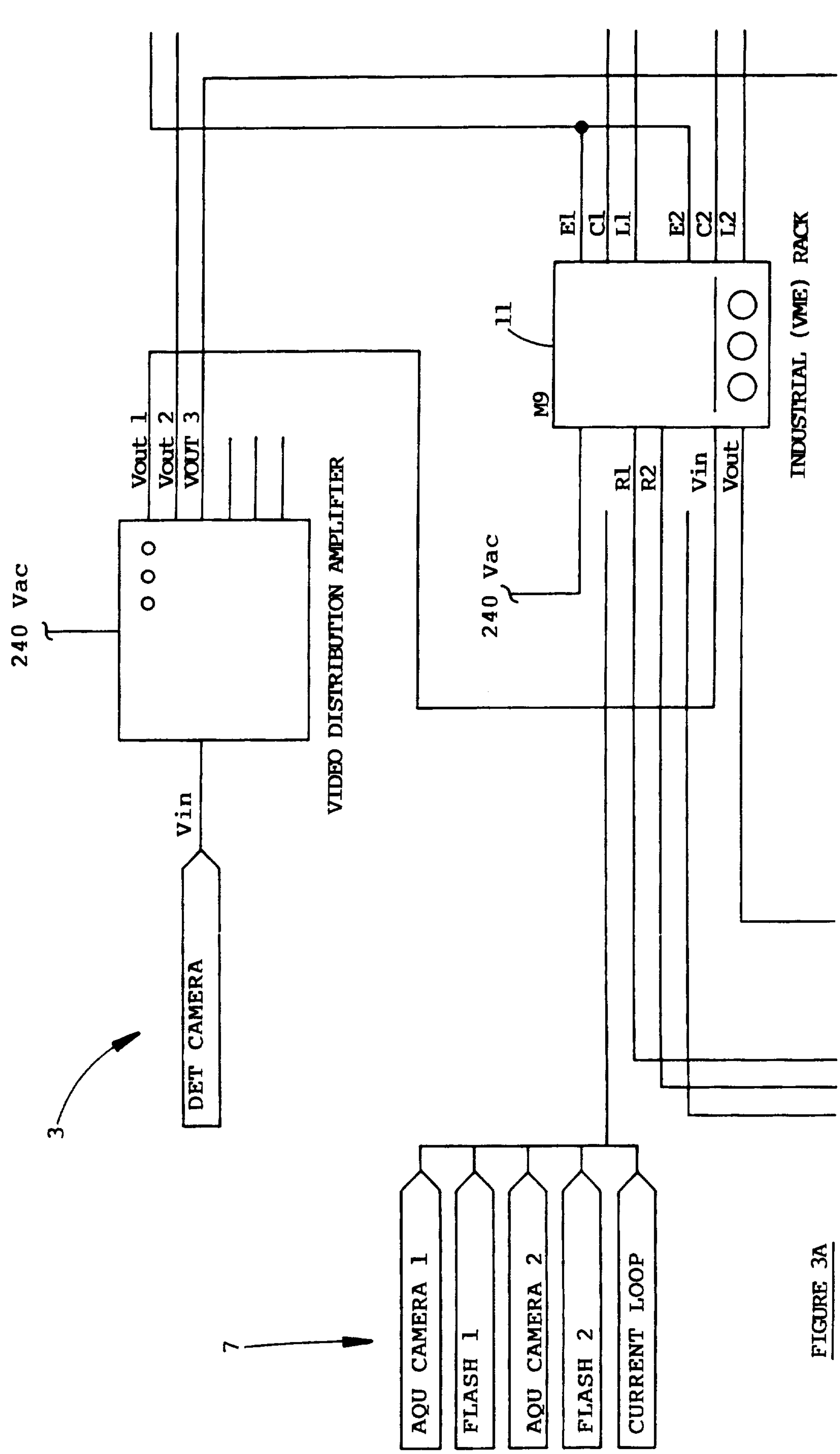

240 Vac
Vin
DET CAMERA
3
VIDEO DISTRIBUTION AMPLIFIER
Vout 1
Vout 2
VOUT 3
240 Vac
11
M9
E1
C1
L1
E2
C2
L2
R1
R2
Vin
Vout
INDUSTRIAL (VME) RACK
7
AQU CAMERA 1
FLASH 1
AQU CAMERA 2
FLASH 2
CURRENT LOOP

FIGURE 3A

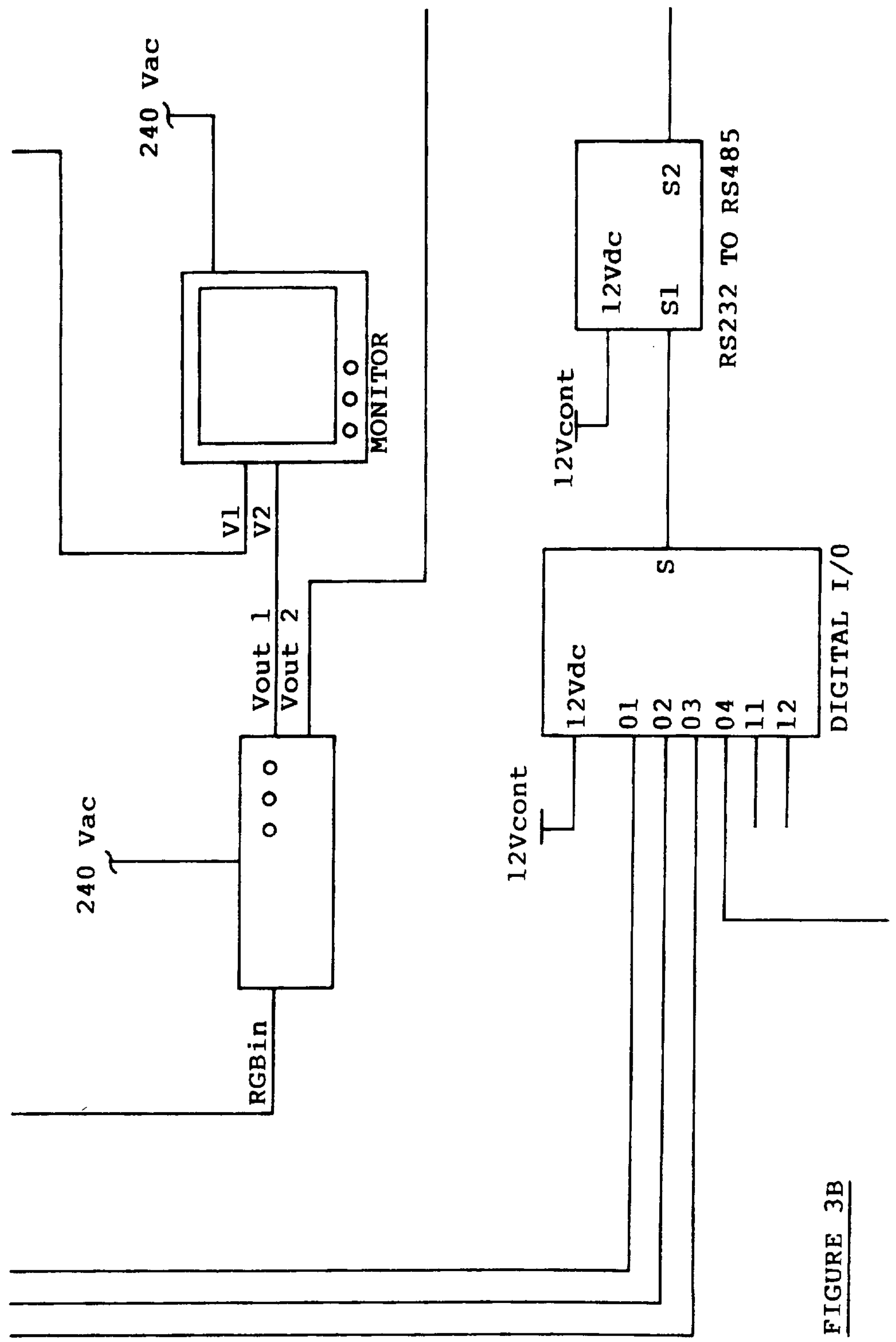
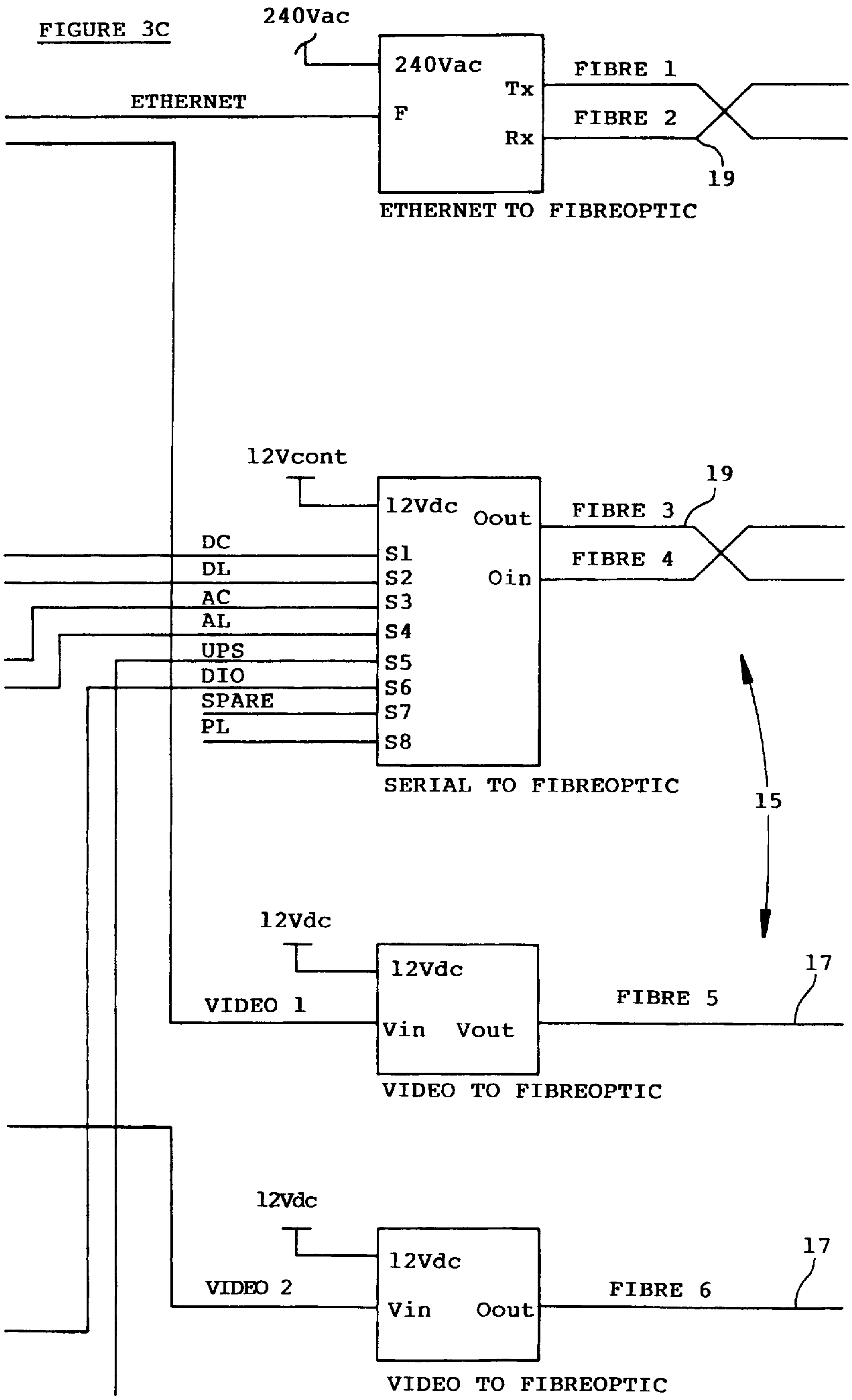

240 Vac
MONITOR
V1
V2
Vout 1
Vout 2
240 Vac
RGBin
12Vdc
S1
S2
RS232 TO RS485
12Vcont
S
DIGITAL I/O
12Vdc
01
02
03
04
11
12
12Vcont

FIGURE 3B

FIGURE 3C


240Vac
240Vac
Tx
F
Rx
ETHERNET
FIBRE 1
FIBRE 2
19
ETHERNET TO FIBREOPTIC
12Vcont
12Vdc
Oout
Oin
FIBRE 3
FIBRE 4
19
DC
DL
AC
AL
UPS
DIO
SPARE
PL
S1
S2
S3
S4
S5
S6
S7
S8
SERIAL TO FIBREOPTIC
15
12Vdc
12Vdc
VIDEO 1
Vin
Vout
FIBRE 5
17
VIDEO TO FIBREOPTIC
12Vdc
12Vdc
VIDEO 2
Vin
Oout
FIBRE 6
17
VIDEO TO FIBREOPTIC

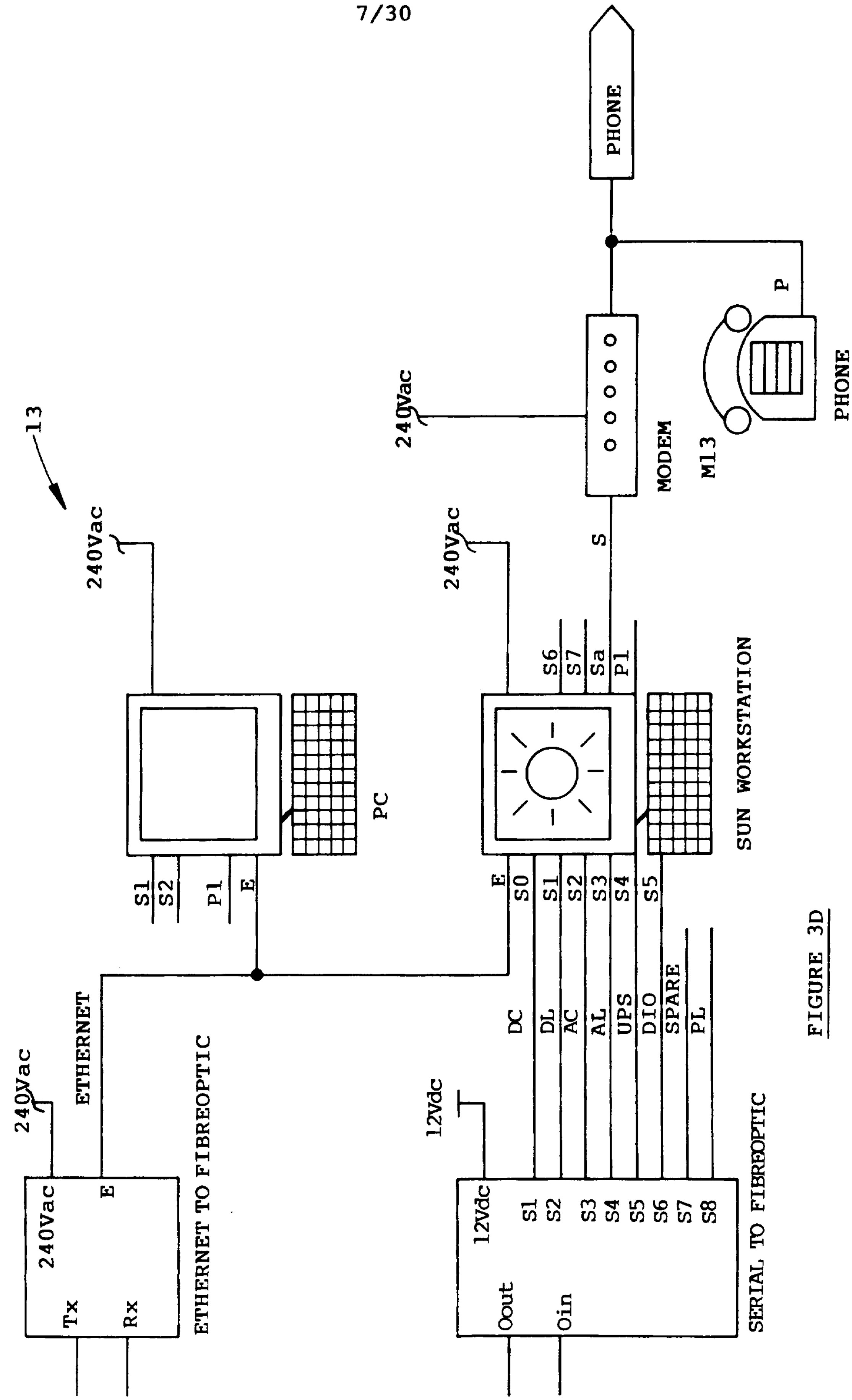

13
240Vac
ETHERNET
ETHERNET TO FIBREOPTIC
Tx
Rx
E
PC
S1
S2
P1
SUN WORKSTATION
S0
S3
S4
S5
S6
S7
Sa
S
MODEM
M13
PHONE
P
12Vdc
DC
DL
AC
AL
UPS
DIO
SPARE
PL
S8
Oout
Oin
SERIAL TO FIBREOPTIC

FIGURE 3D

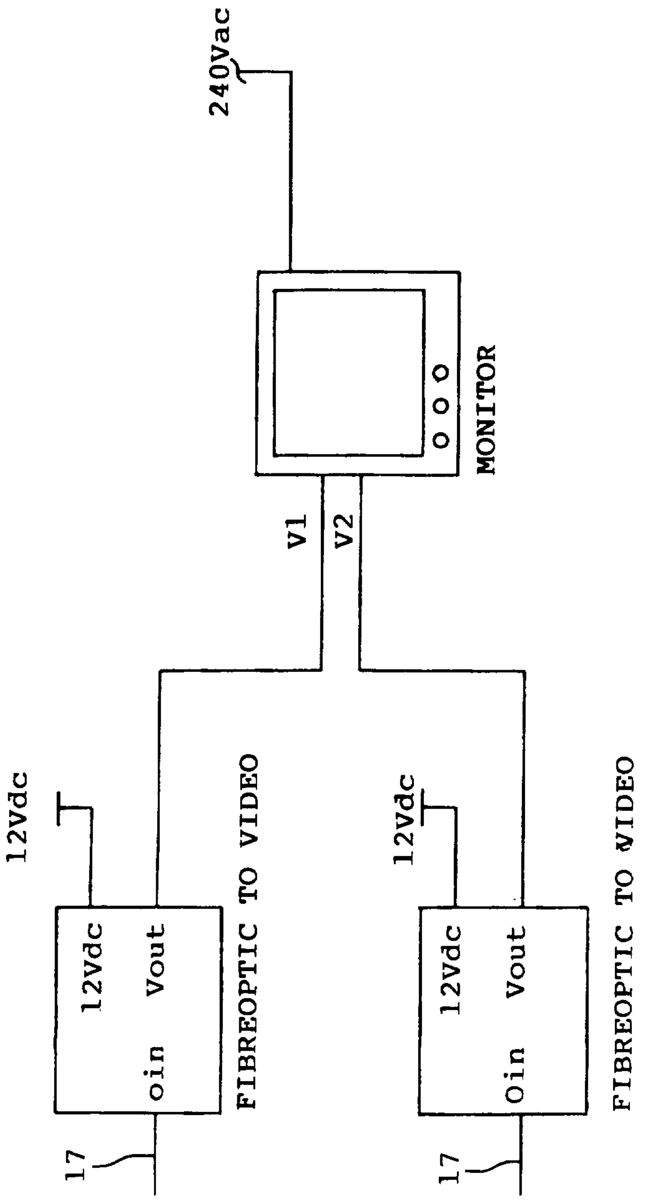

240Vac
MONITOR
V1
V2
12Vdc
12Vdc
Vout
oin
FIBREOPTIC TO VIDEO
17
12Vdc
12Vdc
Vout
Oin
FIBREOPTIC TO VIDEO
17

FIGURE 3E

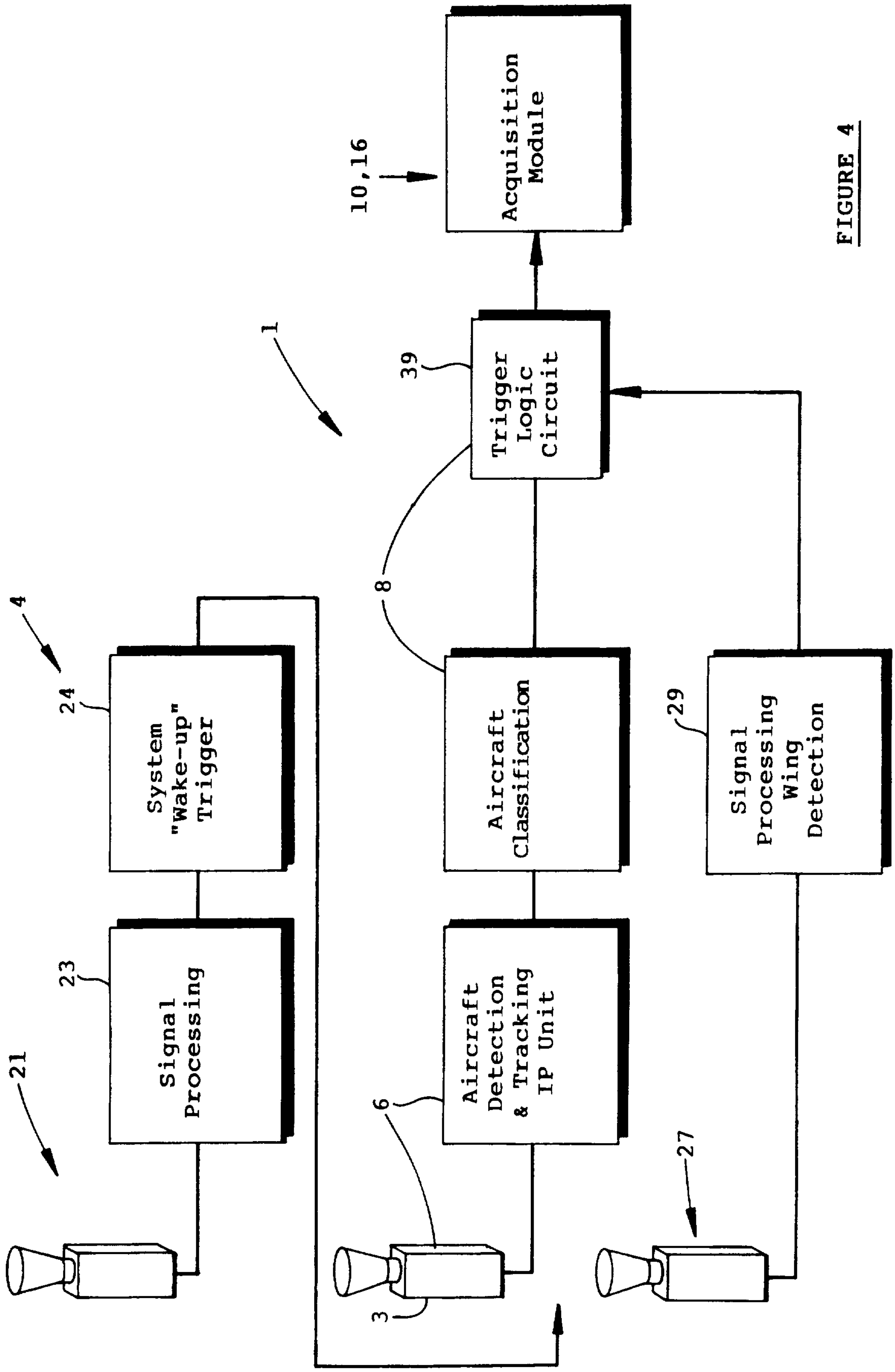

Acquisition Module
10,16
1
39
Trigger Logic Circuit
8
4
24
System "Wake-up" Trigger
Aircraft Classification
29
Signal Processing Wing Detection
23
Signal Processing
21
6
Aircraft Detection & Tracking IP Unit
27
3

FIGURE 4

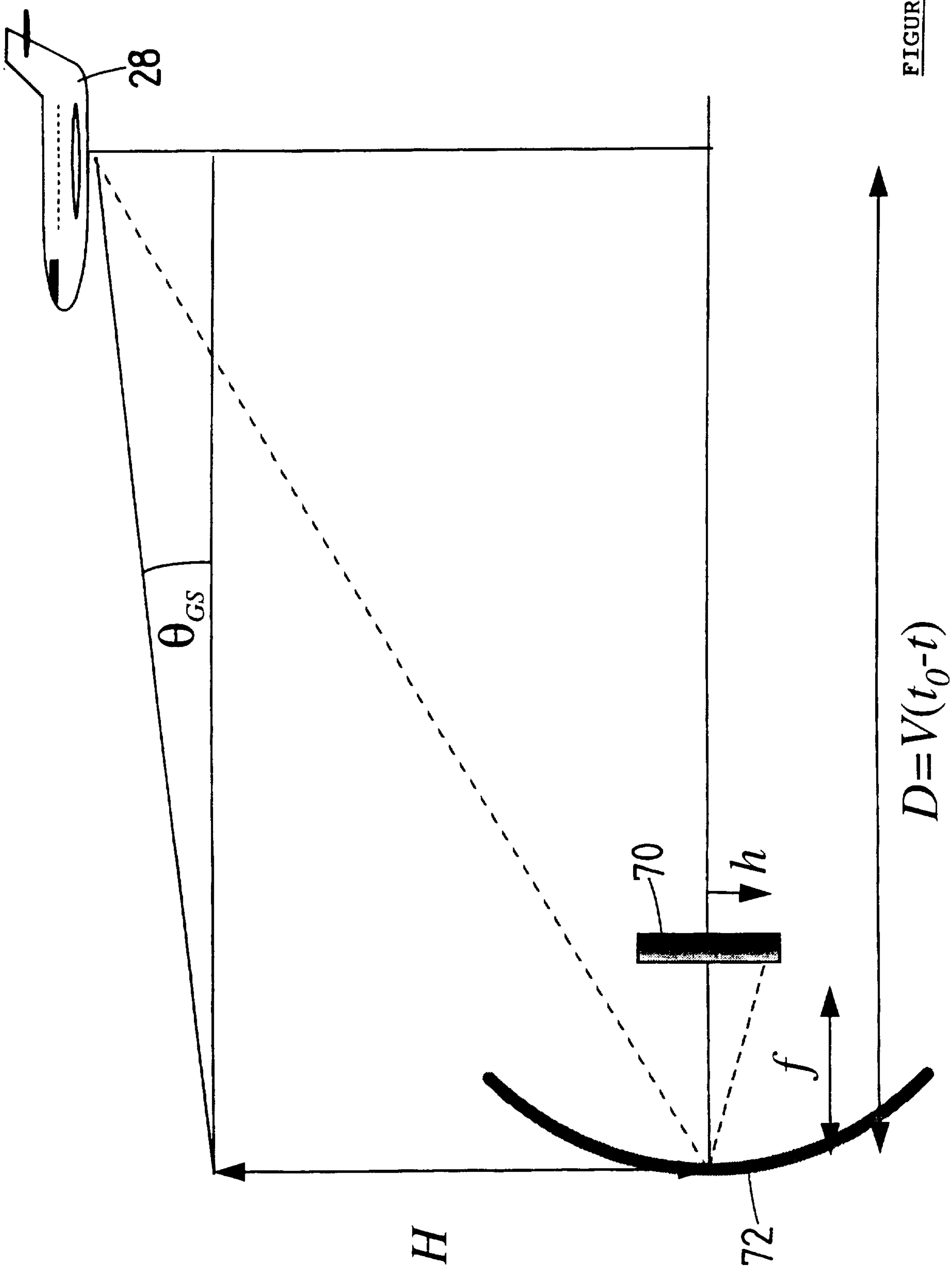


FIGURE 5

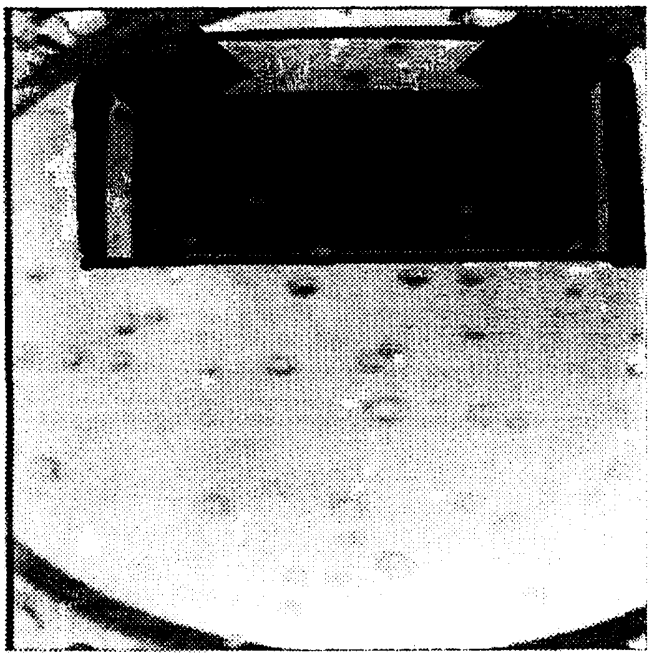


Figure 6a

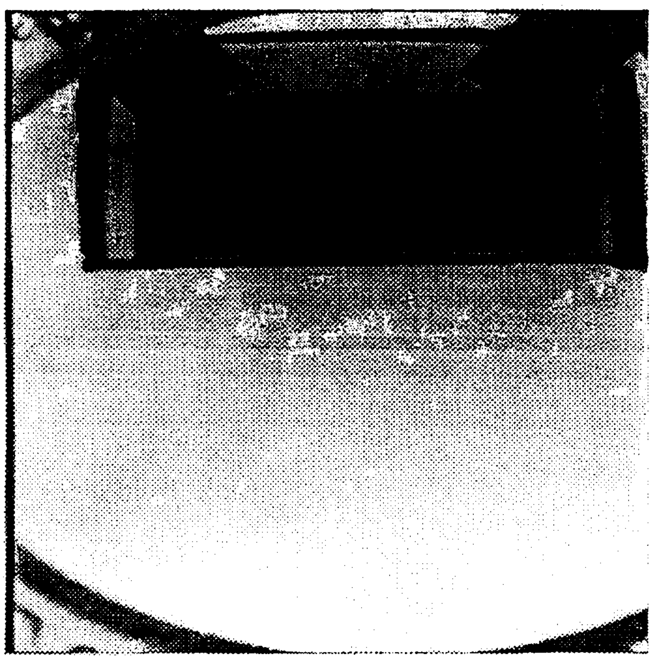


Figure 6b

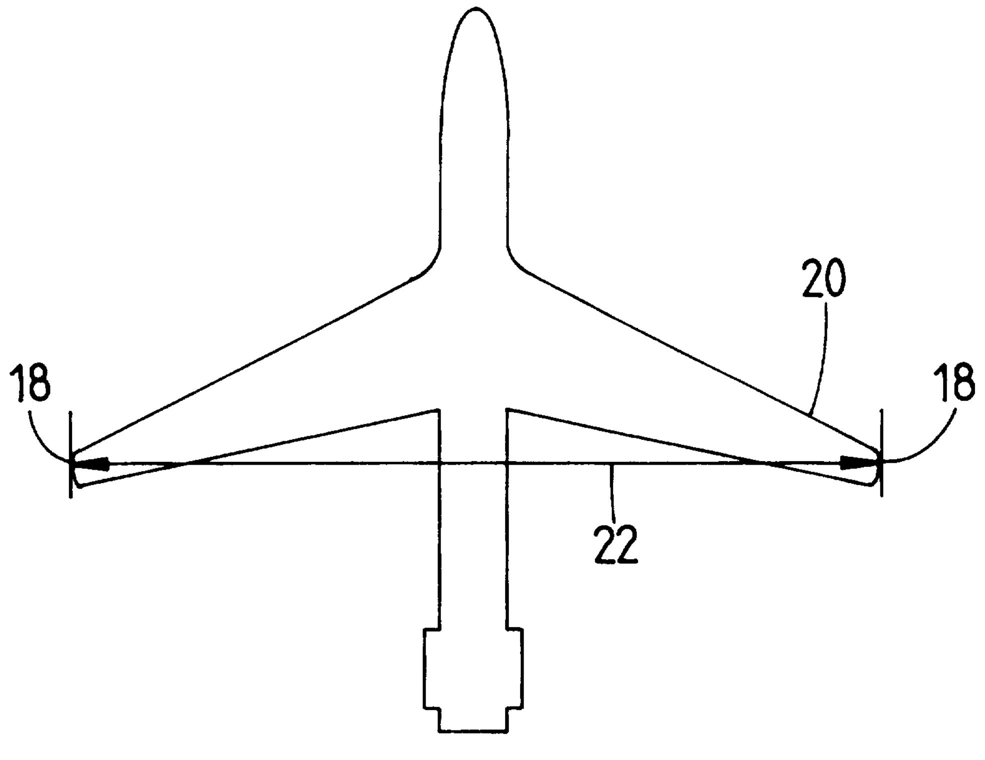


FIGURE 7

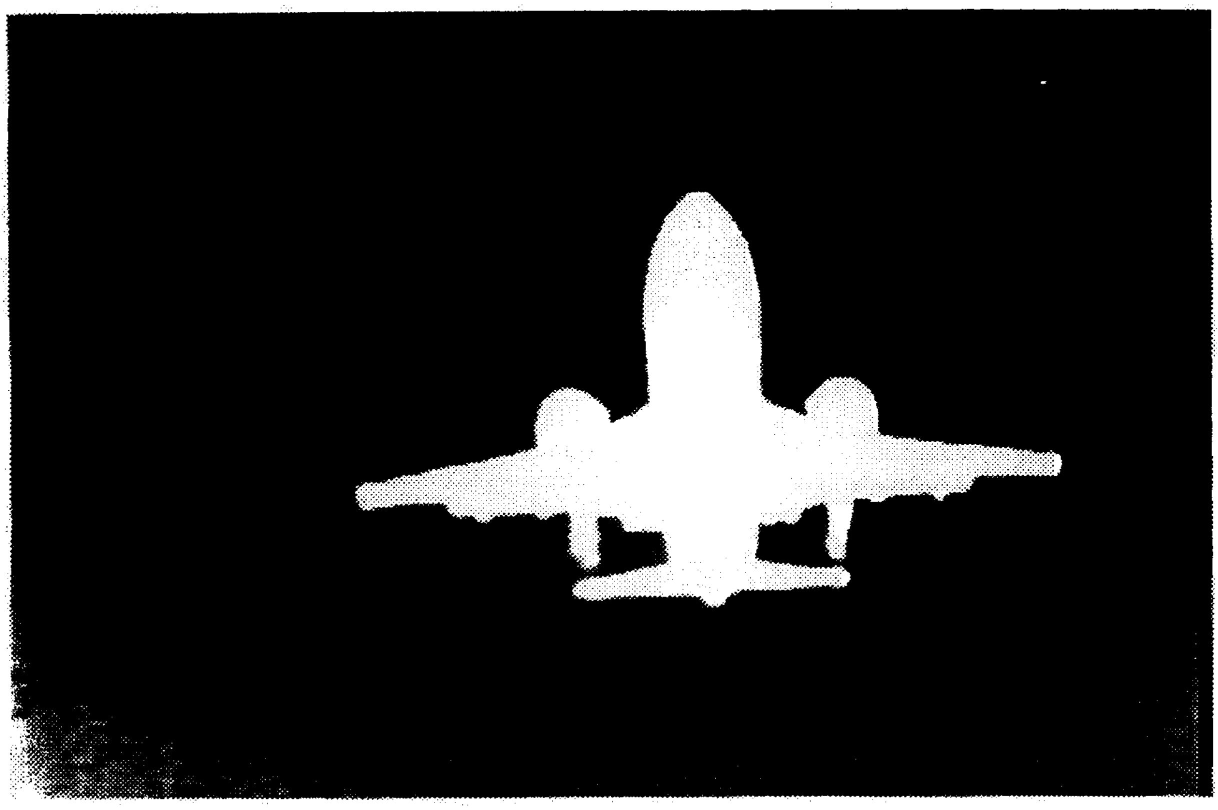
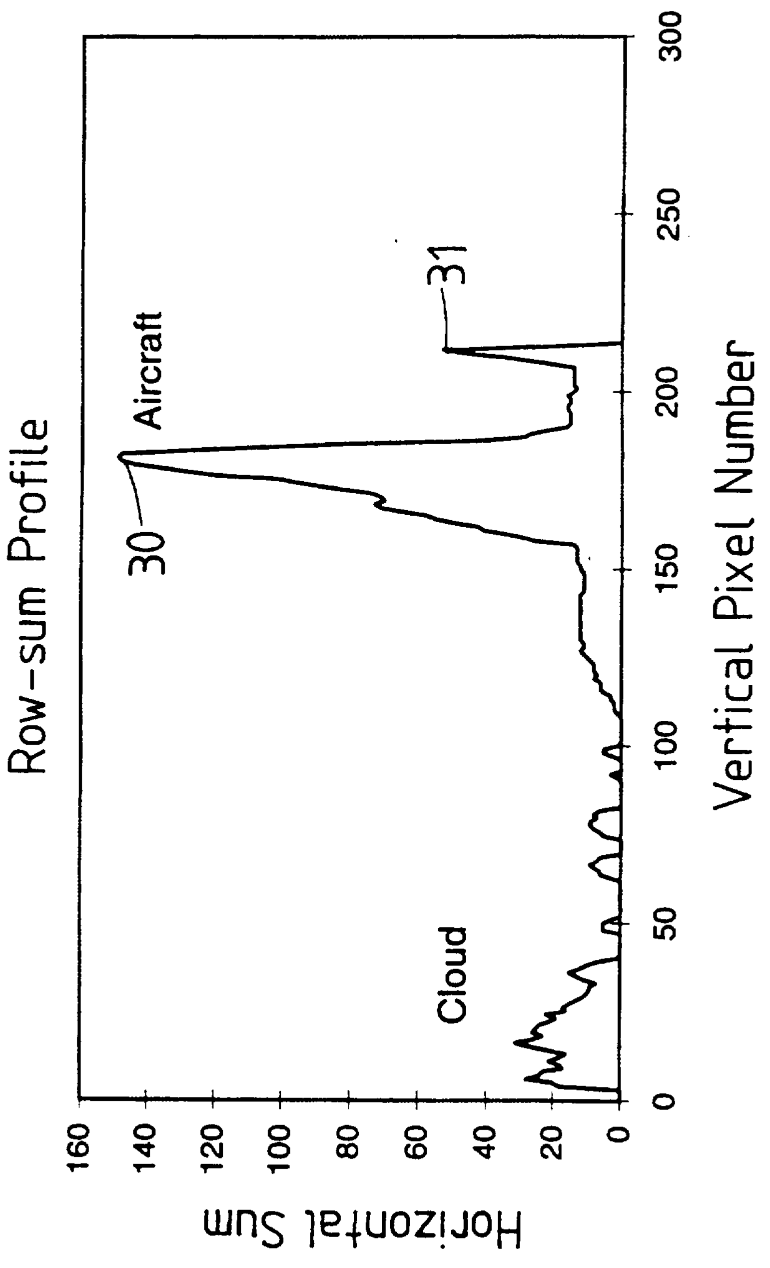


Figure 8

Figure 9

FIGURE 10


Row-sum Profile
Horizontal Sum
Vertical Pixel Number
Aircraft
Cloud
30
31
160
140
120
100
80
60
40
20
0
0
50
100
150
200
250
300

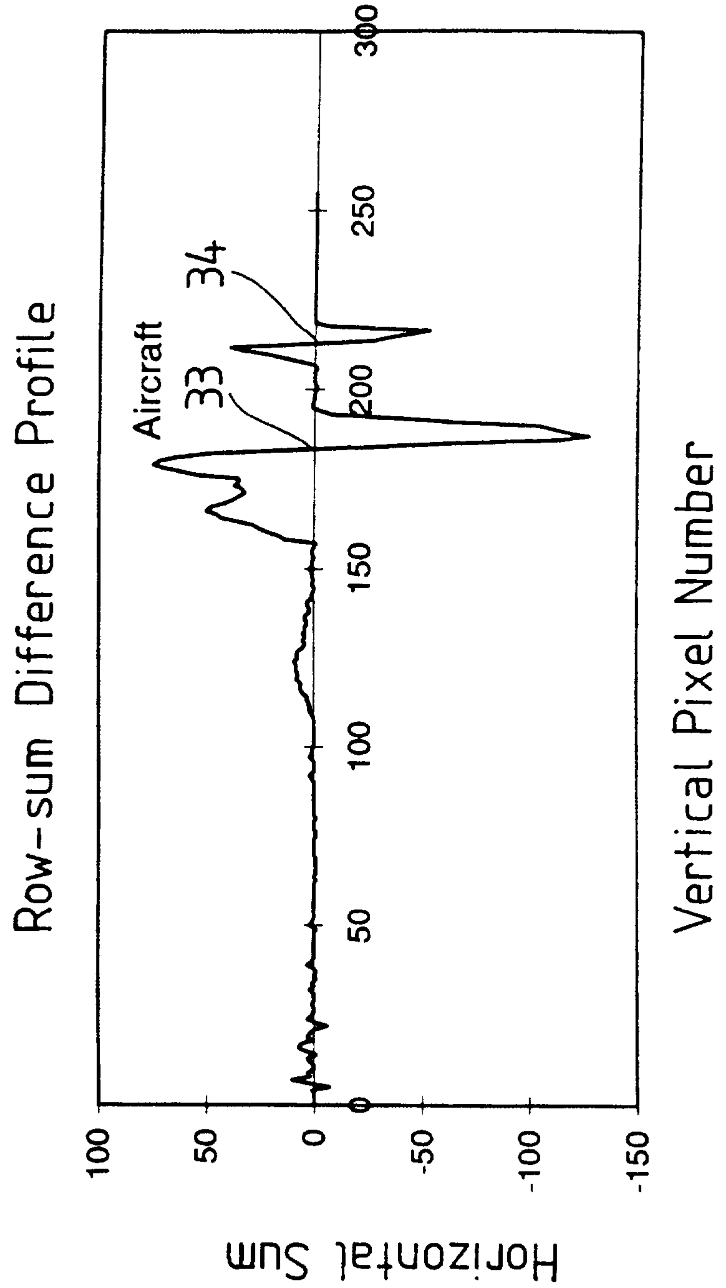

Row-sum Difference Profile
Aircraft
33
34
Horizontal Sum
100
50
0
-50
-100
-150
0
50
100
150
200
250
300
Vertical Pixel Number

FIGURE 11

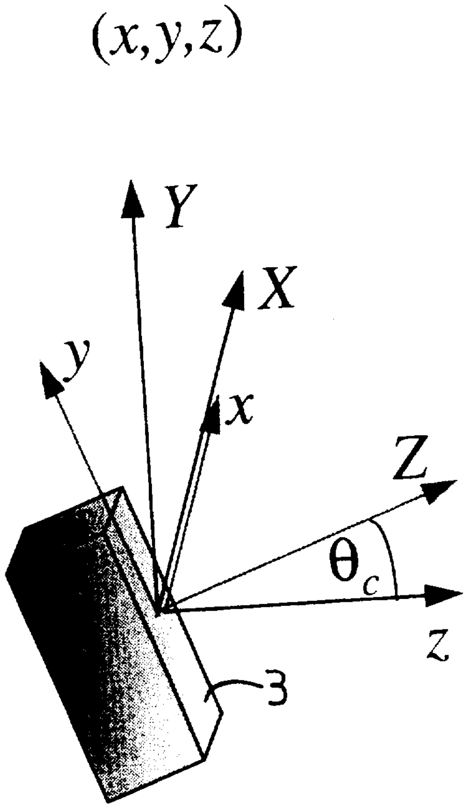


FIGURE 12

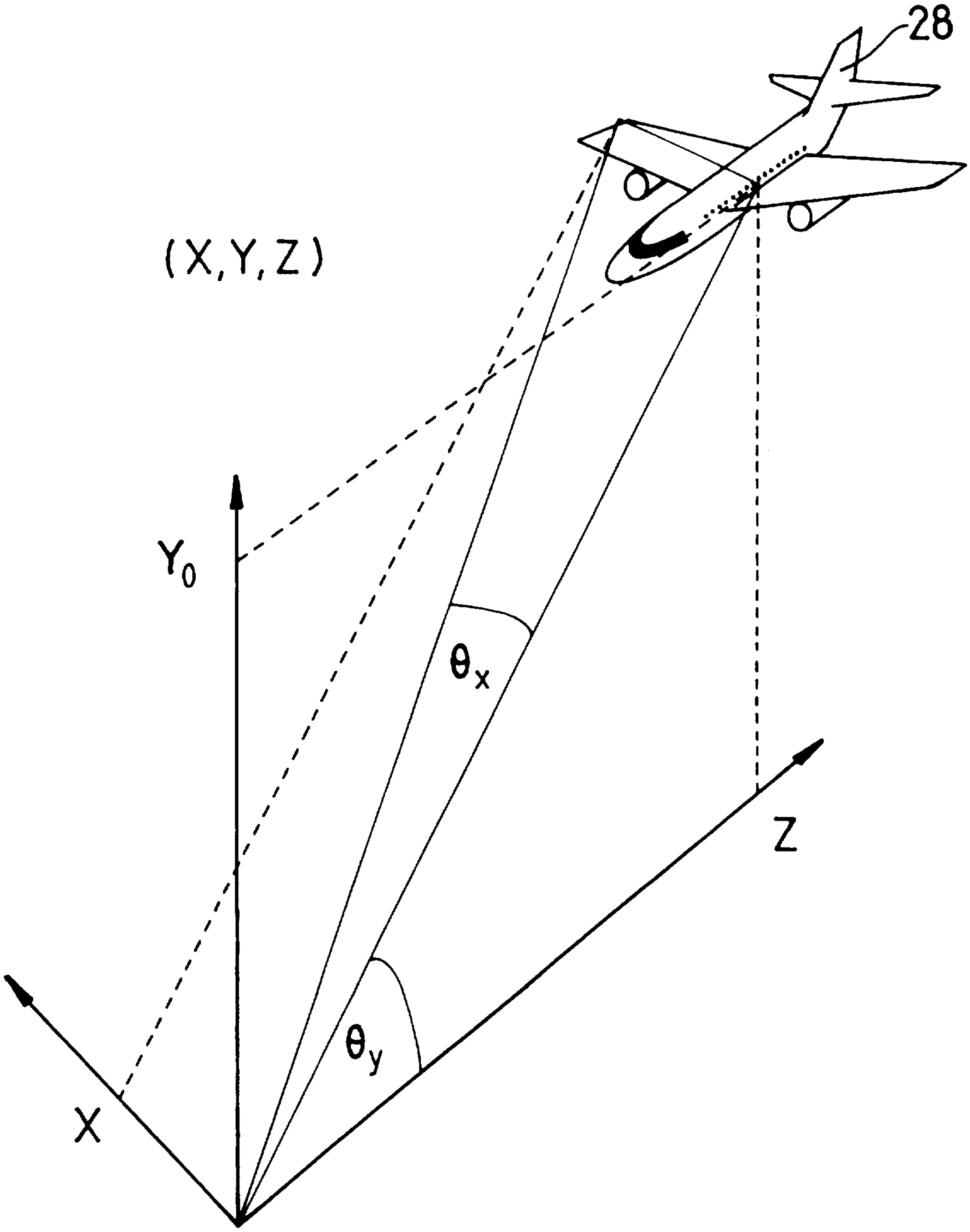


FIGURE 13

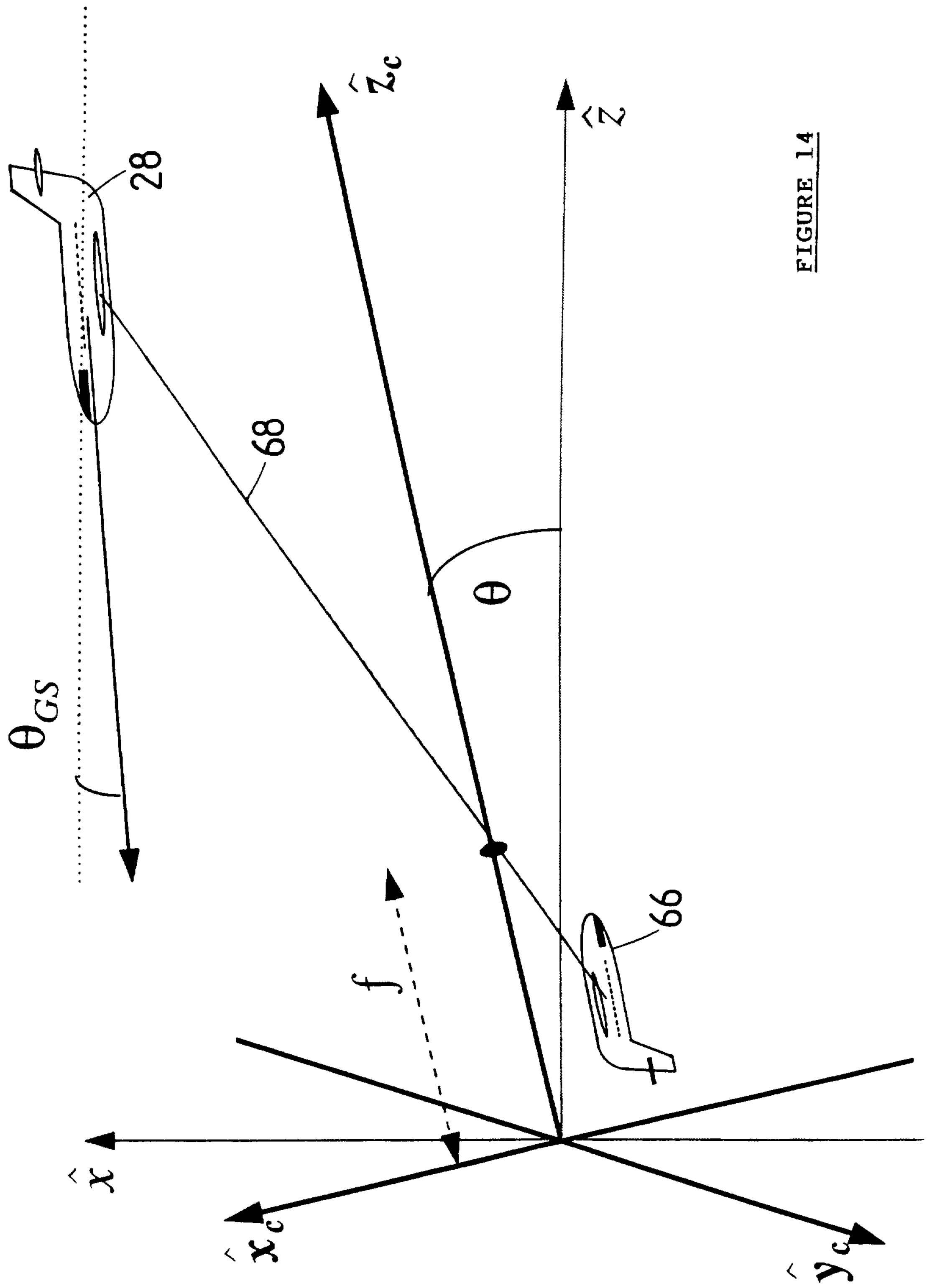
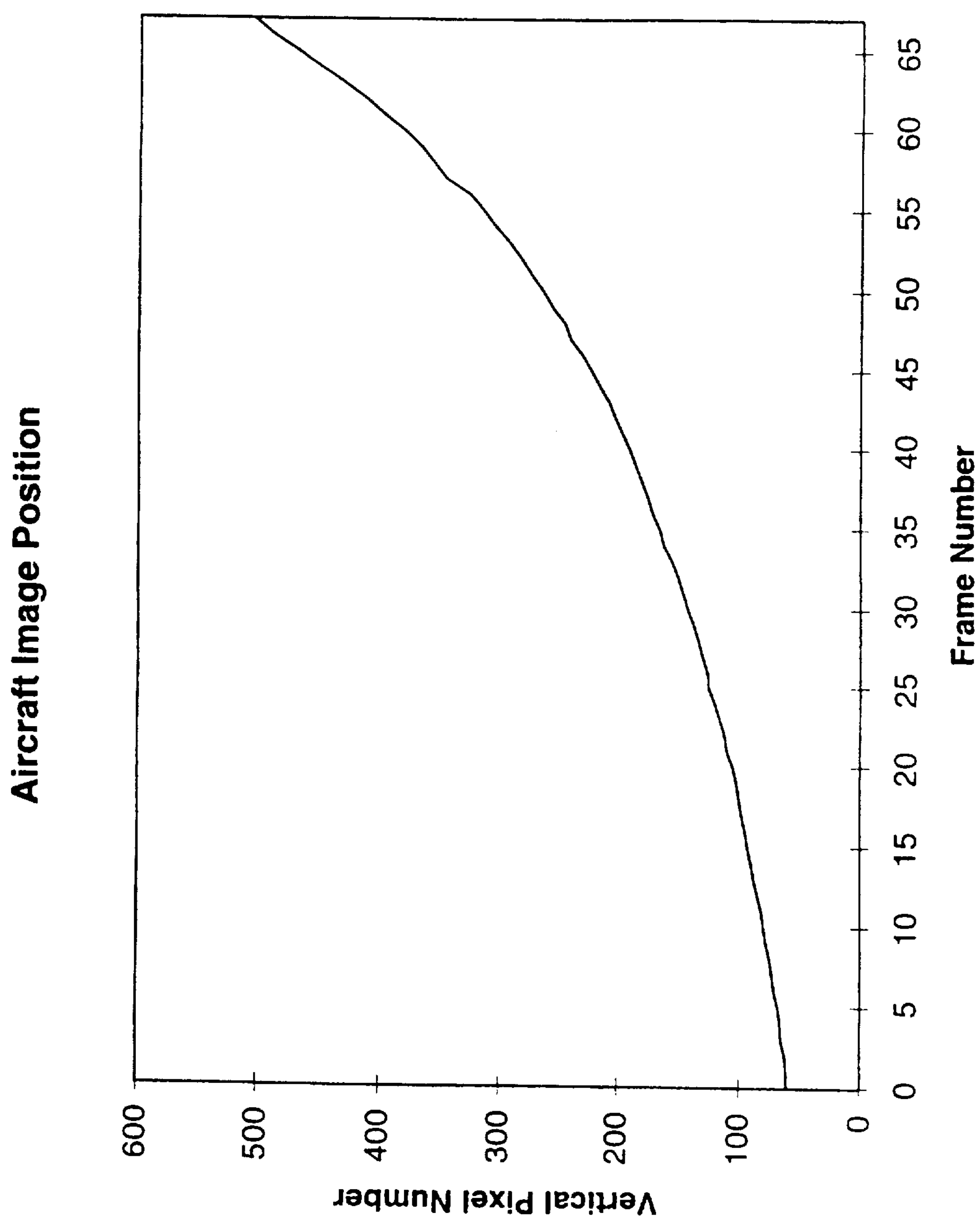


FIGURE 14

FIGURE 15


Aircraft Image Position
Vertical Pixel Number
600
500
400
300
200
100
0
Frame Number
0
5
10
15
20
25
30
35
40
45
50
55
60
65

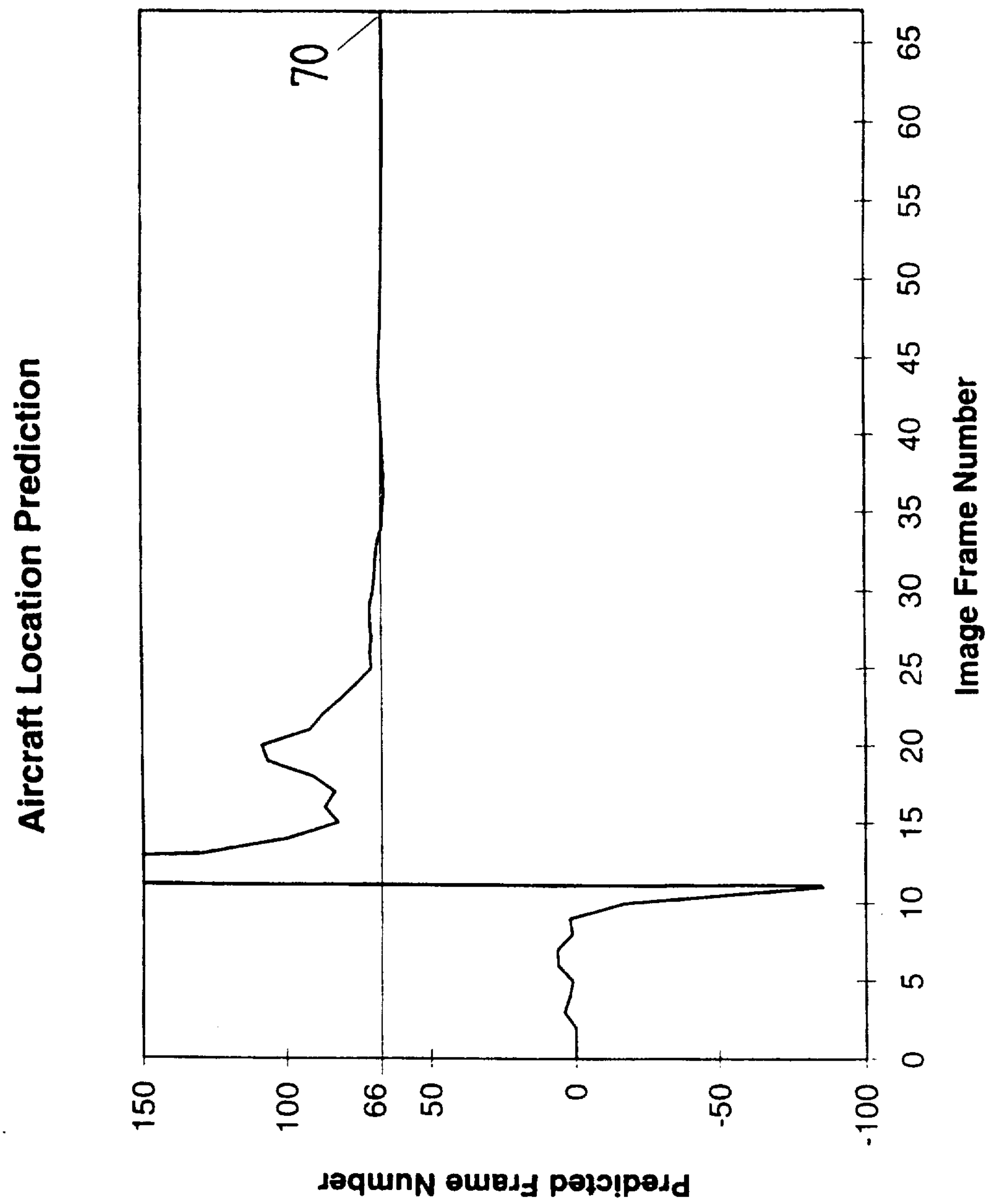

Aircraft Location Prediction
Predicted Frame Number
150
100
66
50
0
-50
-100
Image Frame Number
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70

FIGURE 16

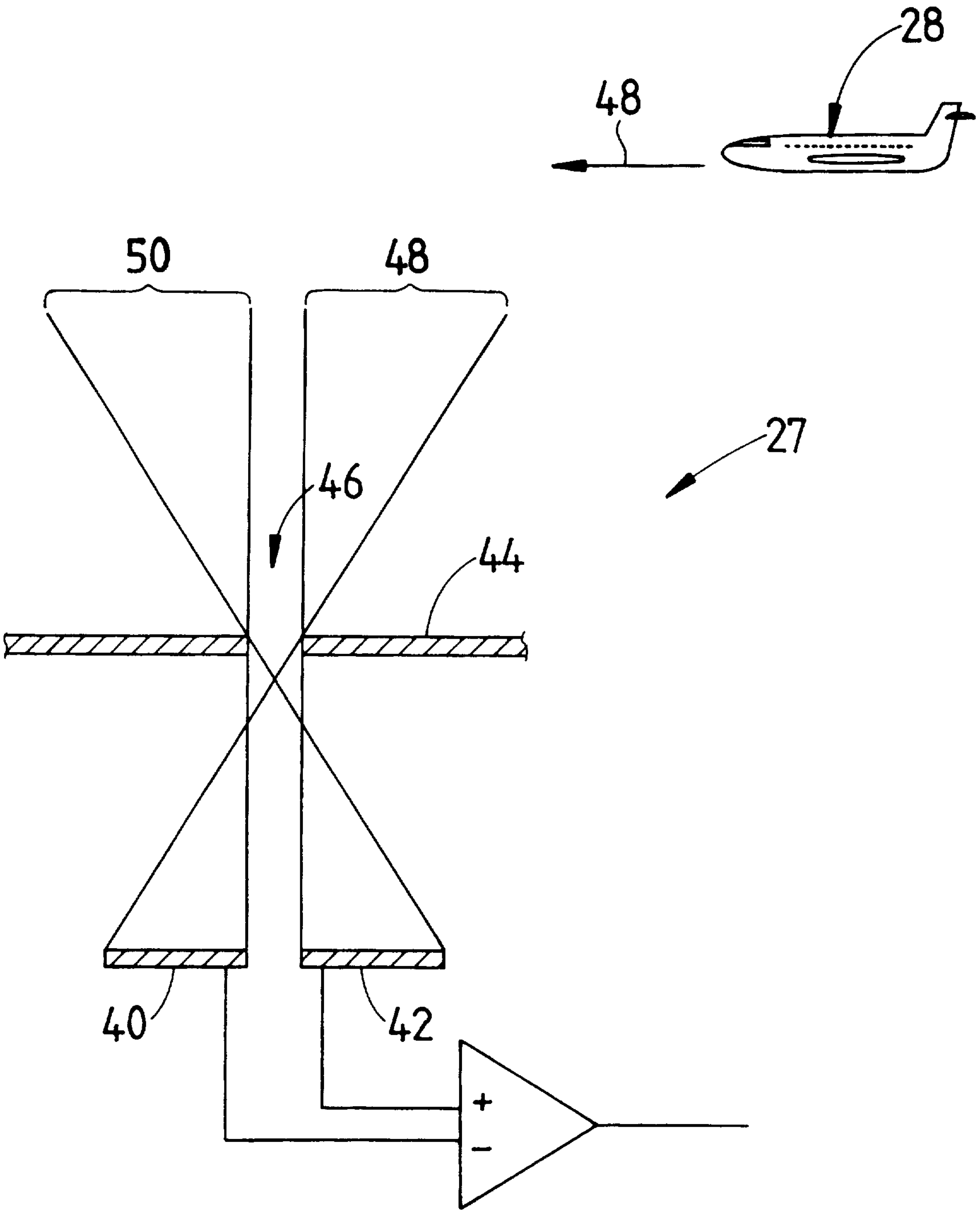


FIGURE 17

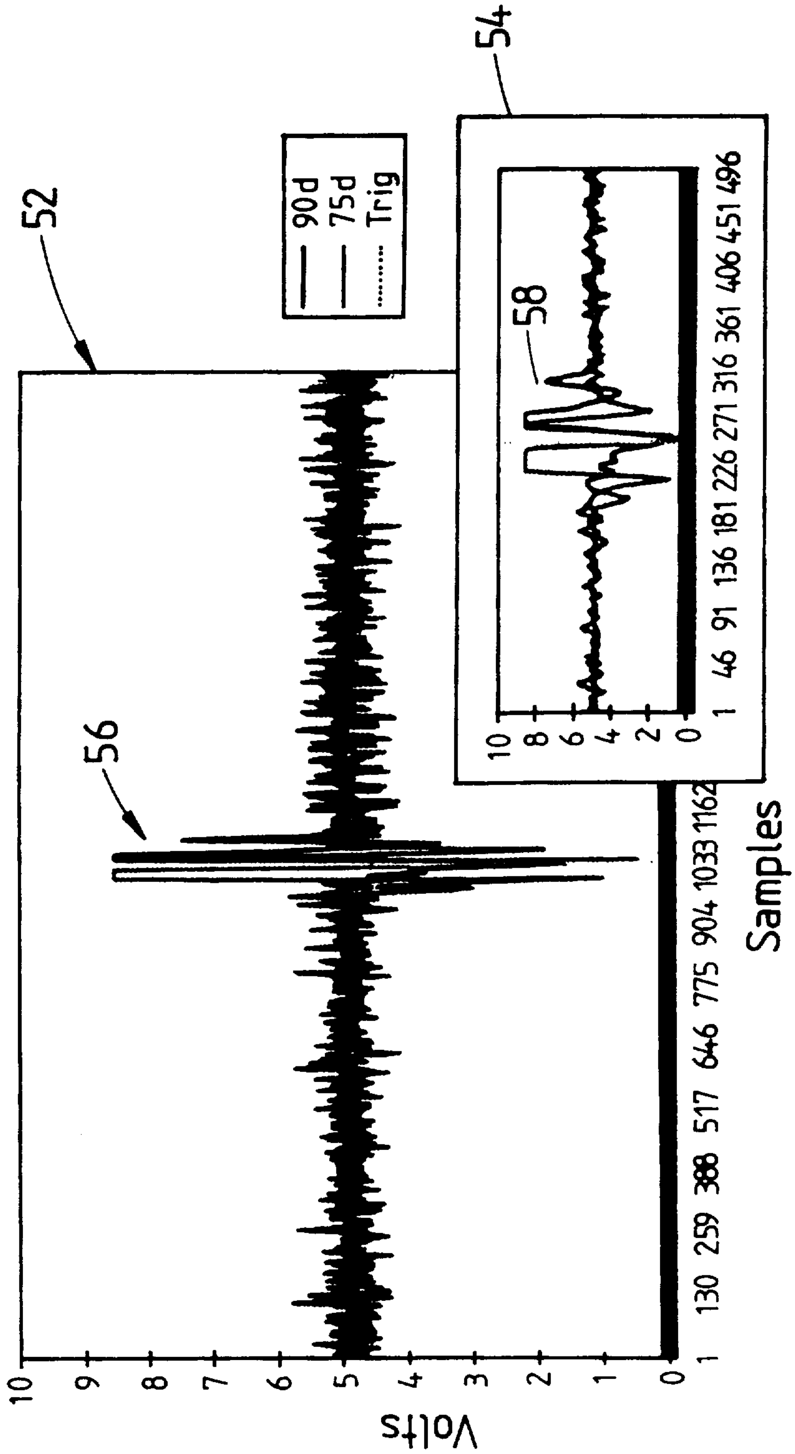

52
54
56
58
90d
75d
Trig
Volts
Samples
10 9 8 7 6 5 4 3 2 1 0
1 130 259 388 517 646 775 904 1033 1162
10 8 6 4 2 0
1 46 91 136 181 226 271 316 361 406 451 496

FIGURE 18

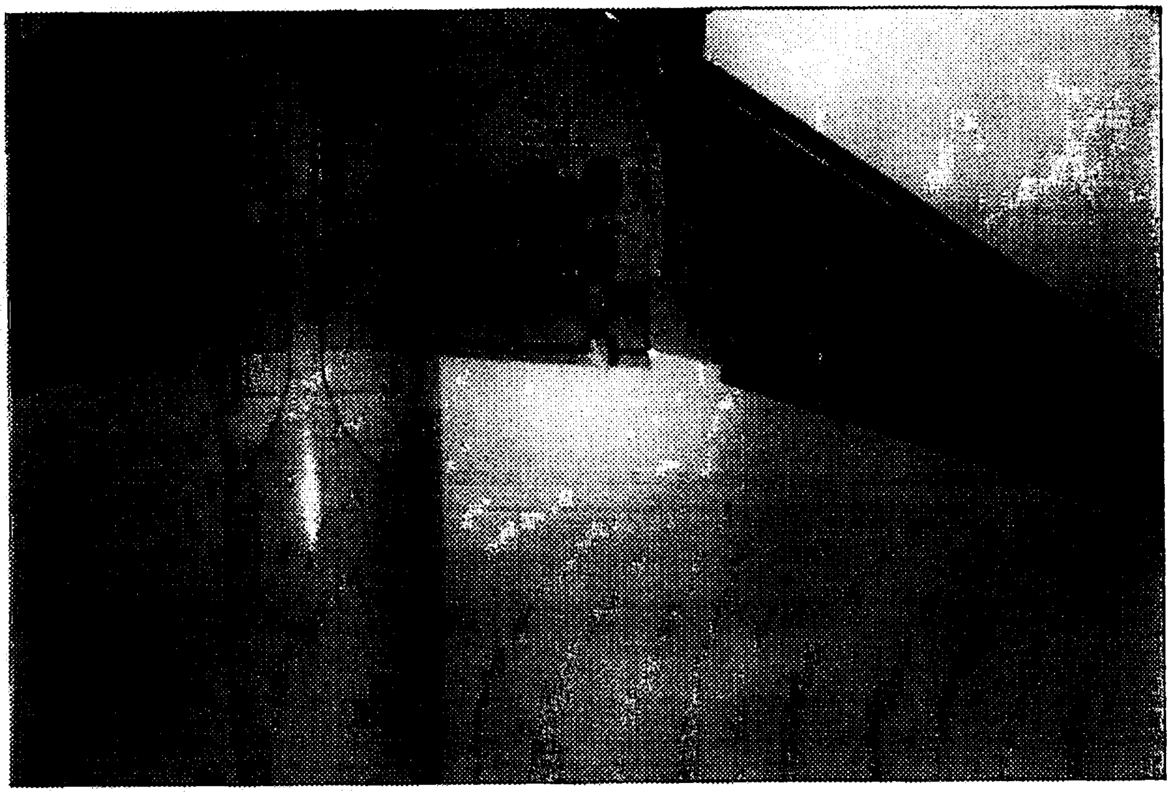


Figure 19

Figure 20

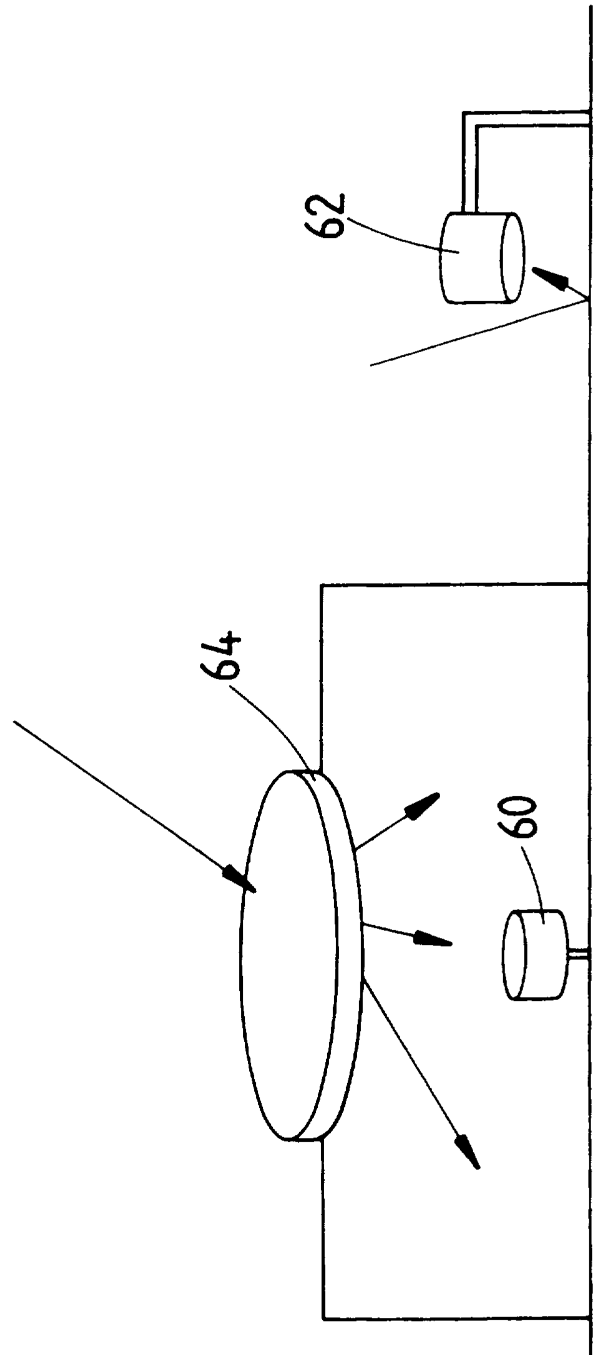


FIGURE 21

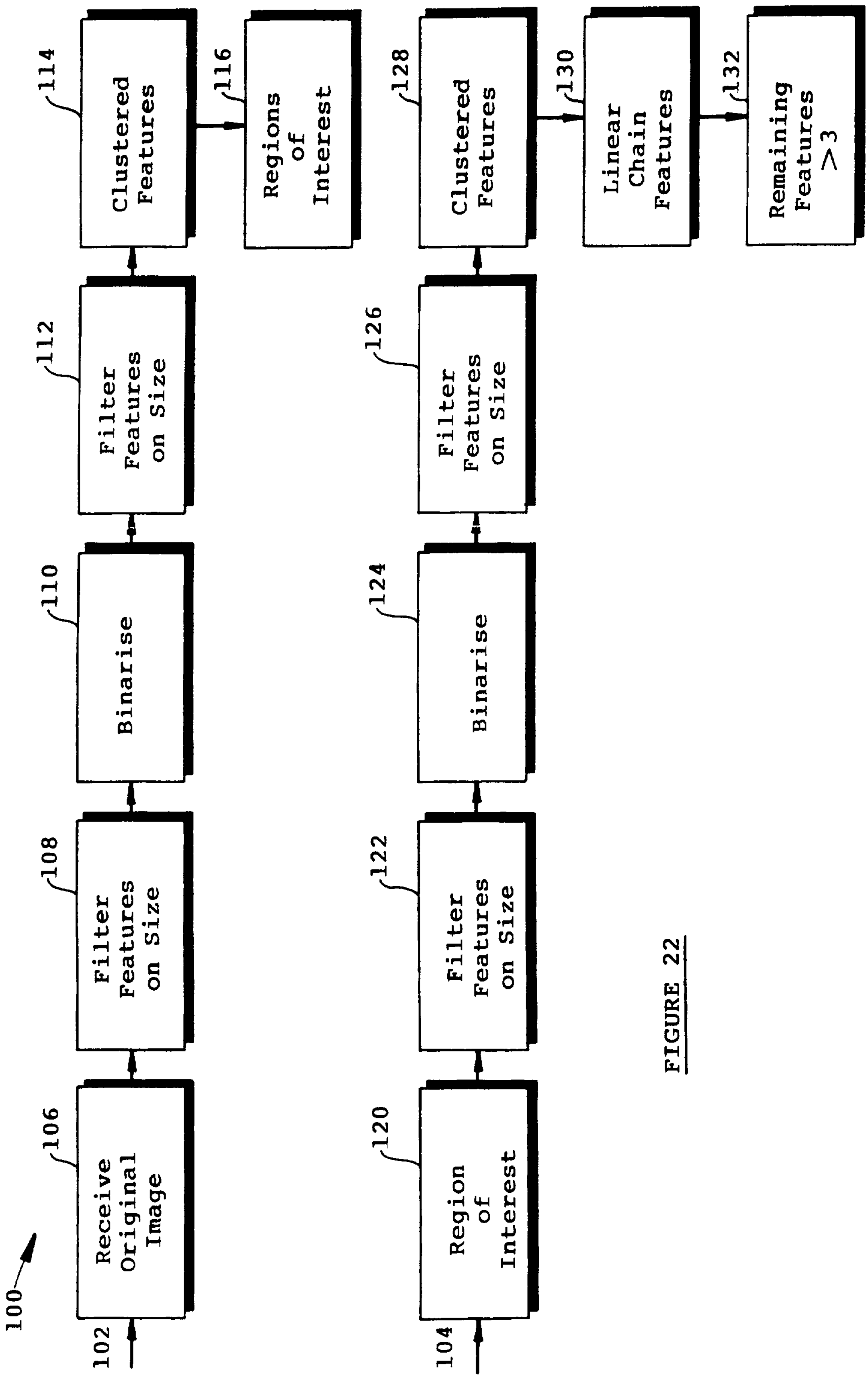

100
102
Receive Original Image
106
Filter Features on Size
108
Binarise
110
Filter Features on Size
112
Clustered Features
114
Regions of Interest
116
104
Region of Interest
120
Filter Features on Size
122
Binarise
124
Filter Features on Size
126
Clustered Features
128
Linear Chain Features
130
Remaining Features >3
132

FIGURE 22

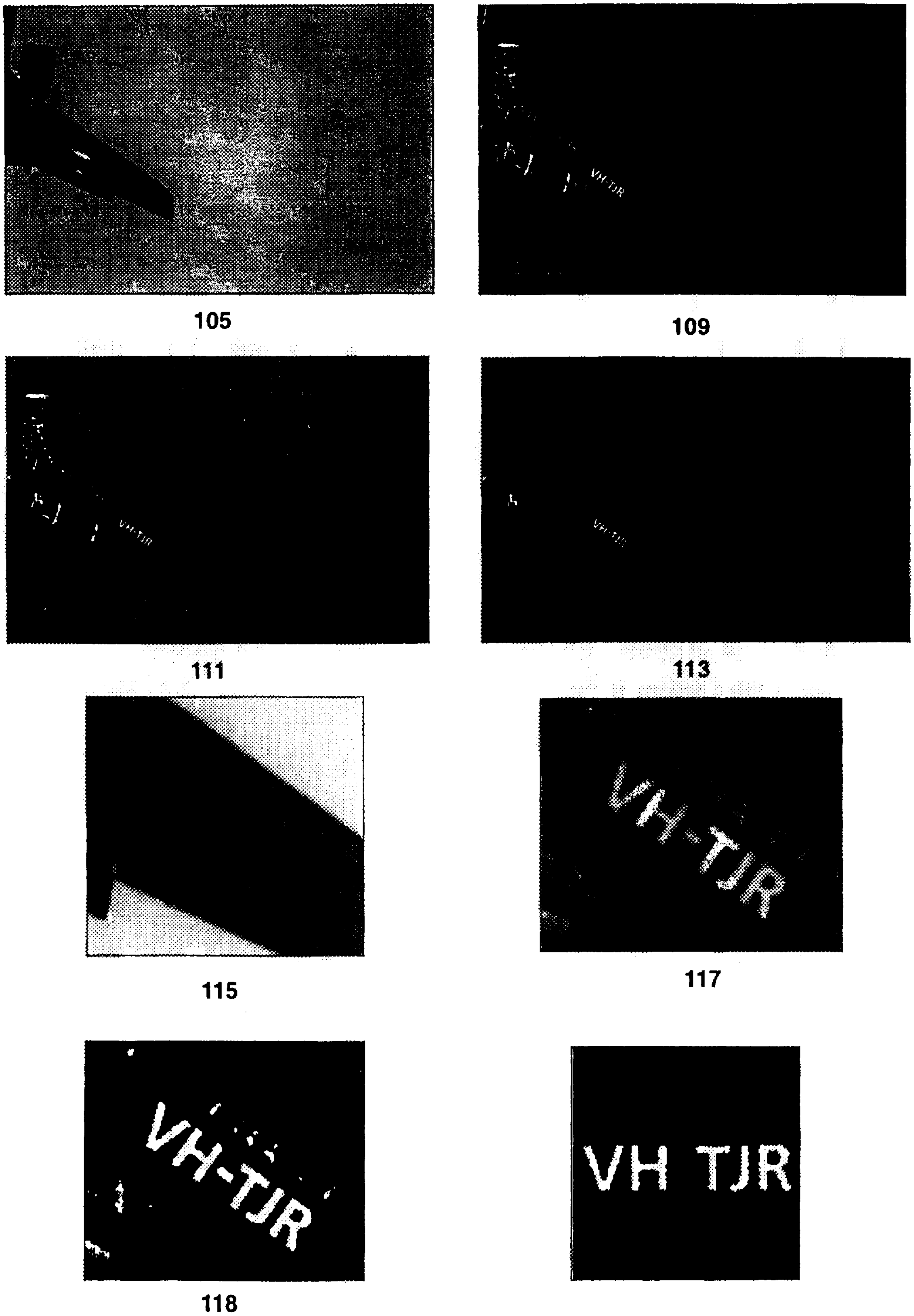


Figure 23

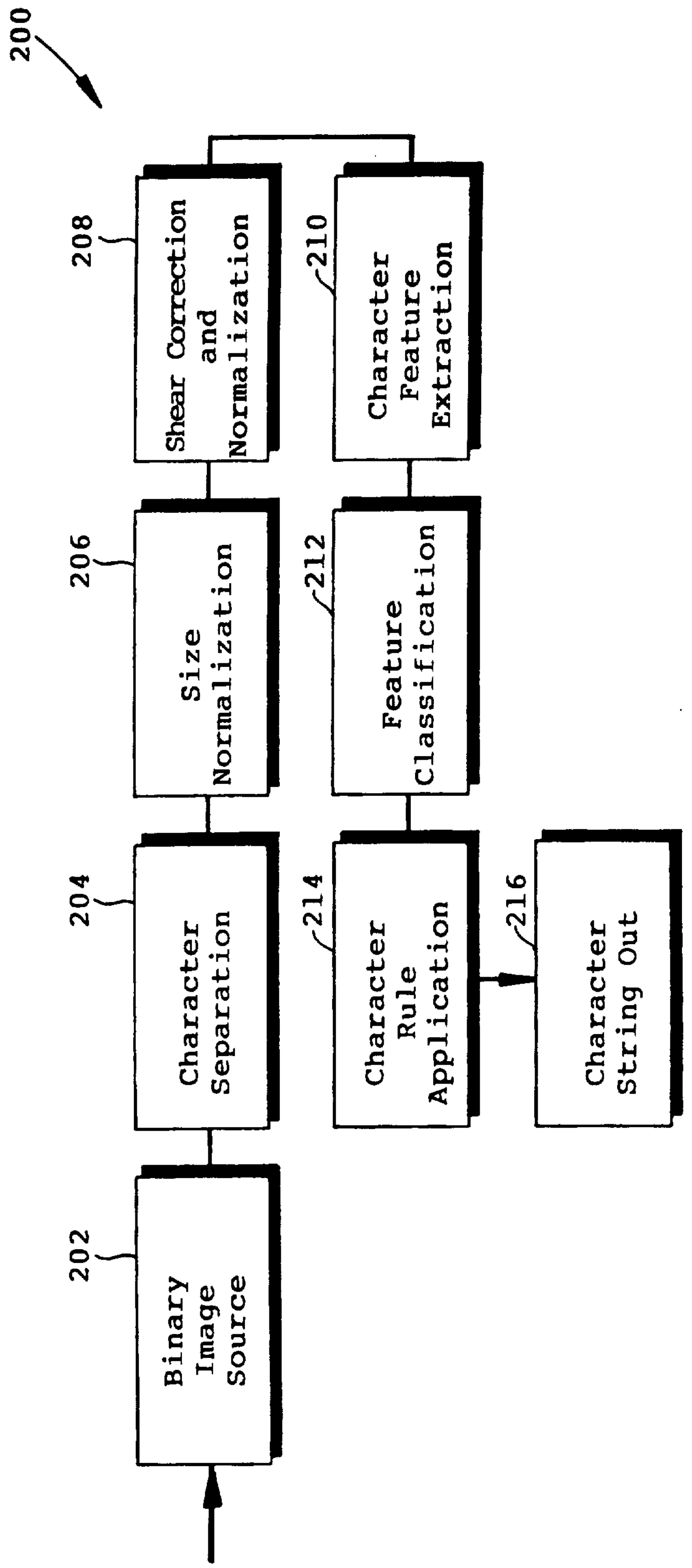

200
202
Binary Image Source
204
Character Separation
206
Size Normalization
208
Shear Correction and Normalization
210
Character Feature Extraction
212
Feature Classification
214
Character Rule Application
216
Character String Out

FIGURE 24

INTERNATIONAL SEARCH REPORT

International Application No.
PCT/AU 97/00198

A. CLASSIFICATION OF SUBJECT MATTER

Int Cl^{6}: G08G 5/00, G01P 3/38, G06T 7/20, G06K 9/78, 9/46

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC as above

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
AU: IPC as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
WPAT, INSC (IMAG:; OBJECT:; DETECT:; POSITION:; MARK, ID:)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 686943- A2 (Matsushita Electric Industrial Co. Ltd.) 13 December 1995, whole document	1, 26, 9, 34
X	US 5,406,501 (U.S. Philips Corp.) 11 April 1995, whole document	1, 7, 9, 32, 34
X	WO 93/19441 (Commonwealth Scientific and Industrial Research Organisation) 30 September 1993 whole document	1-4, 16, 17, 19, 20 26-29, 41, 42, 44, 45

[X] Further documents are listed in the continuation of Box C

[X] See patent family annex

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
9 May 1997	21 MAY 1997

Name and mailing address of the ISA/AU
AUSTRALIAN INDUSTRIAL PROPERTY ORGANISATION
PO BOX 200
WODEN ACT 2606
AUSTRALIA Facsimile No.: (06) 285 3929

Authorized officer

Dale Siver

Telephone No.: (06) 283 2196

INTERNATIONAL SEARCH REPORT

International Application No.
PCT/AU 97/00198

C (Continuation)	DOCUMENTS CONSIDERED TO BE RELEVANT	
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 5,243,418 (K.K. Toshiba, Kawasaki) 7 September 1993, whole document	1, 26, 9, 34 10, 35
X Y	AU-35311/93-B (Iconix Pty Ltd) 8 July 1993, whole document especially page 21, lines 11-26	16, 41 21, 46
X	US 5, 134, 472 (K.K. Toshiba) 28 July 1992, whole document	1, 9, 26, 34
X Y	GB 2,227,589 A (Image Recognition Equipment Corp.) 1 August 1990 Abstract, Summary pages 1-4, Figures	16, 41 21, 46
X	WO 90/01706 (Hughes Aircraft Co.) 22 February 1990, whole document	1, 5, 6, 9, 10, 26, 30, 31, 34, 35
Y	WO 93/21617 (Traffic Technology Ltd.) 28 October 1993, whole document	1, 2, 26, 27
A	WO 96/12265 (Airport Technology in Scandinavia) 25 April 1996, Abstract Figures	5, 23, 26, 48

INTERNATIONAL SEARCH REPORT

International Application No.
PCT/AU 97/00198

Box 1 Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a)

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. An object detection system using passive sensor to obtain a differential signature representative of the position of moving object. (No image acquisition or analysis.) Claims 1, 5-10, 26, 34, 35, 38.

2. An image acquisition system and analysis system to locate a region in an image including markings identifying said object and processing said region to extract said markings for recognition. (No position or movement detection.) Claims 16-22, 41-47.

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No.
PCT/AU 97/00198

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
EP	686943	CA	2151079	JP	7336694	US	5606376
US	5406501	EP	492724	FR	2670978	JP	4307681
WO	9319441	AU	37402/93	EP	631683	JP	7505966
		NZ	249799				
US	5243418	JP	4192781	JP	5046771		
AU	35311/93	AU	37398/93	WO	9319429		
US	5134472	JP	2207381	JP	2214989		
GB	2227589	FR	2642542	JP	2282881	US	4958064
WO	9001706	AU	44005/89	CA	1313704	DE	68910498
		EP	380658	ES	2016049	IL	90898
		JP	3502018	NO	901560	TR	25266
		US	4937878				
WO	9321617	AU	39599/93	GB	2266398		
WO	9612265	AU	11251/95				

END OF ANNEX