United States Patent [19]

Hardy et al.

[11] **3,811,011**

[45] **May 14, 1974**

[54] **MULTIPLE IMAGE REGISTRATION SYSTEM**

[75] Inventors: **John W. Hardy**, Lexington; **Donald C. Redpath**, Winchester, both of Mass.; **Gilbert Hobrough**, Vancouver, British Columbia, Canada

[73] Assignee: **Itek Corporation**, Lexington, Mass.

[22] Filed: **July 8, 1969**

[21] Appl. No.: **839,940**

[52] **U.S. Cl.** **178/6.8**, 178/6.5, 250/558, 356/2, 356/167

[51] **Int. Cl.** ... **G01c 11/18**, G01b 11/24, H04n 7/18

[58] **Field of Search** .... 178/6.5, 6.8, 7.7; 356/2, 356/167; 250/220 SP, 558

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Primary Examiner—Howard W. Britton
Attorney, Agent, or Firm—Homer O. Blair; Robert L. Nathans; William C. Roch

[57] **ABSTRACT**

A multiple image registration system utilizing scanning patterns with orthogonally related scanning paths parallel to the directions of transformation introduced for correcting *x* and *y*-parallax. A cross-correlation signal indicative of correlation quality is separated into *x* and *y*-components uniquely representing correlation quality in each direction of scan. The separate components are used appropriately to effect relevant control of raster size, model profiling velocity, and both loop gains and operability of *x* and *y*-parallax transformation mechanisms.

35 Claims, 17 Drawing Figures

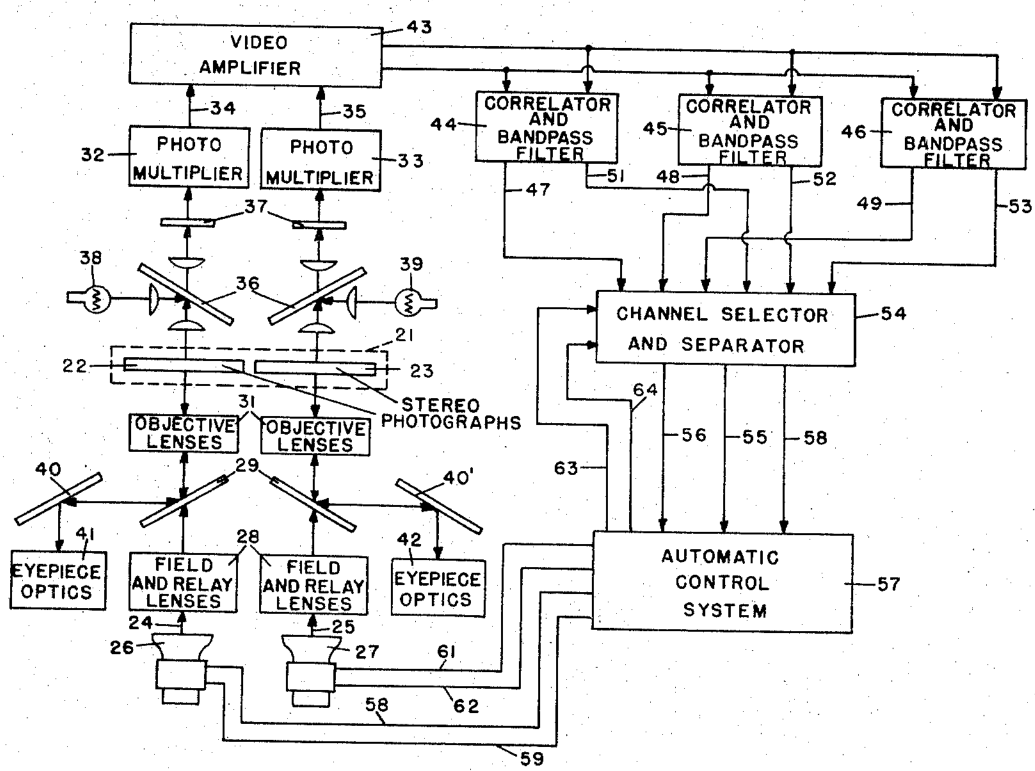
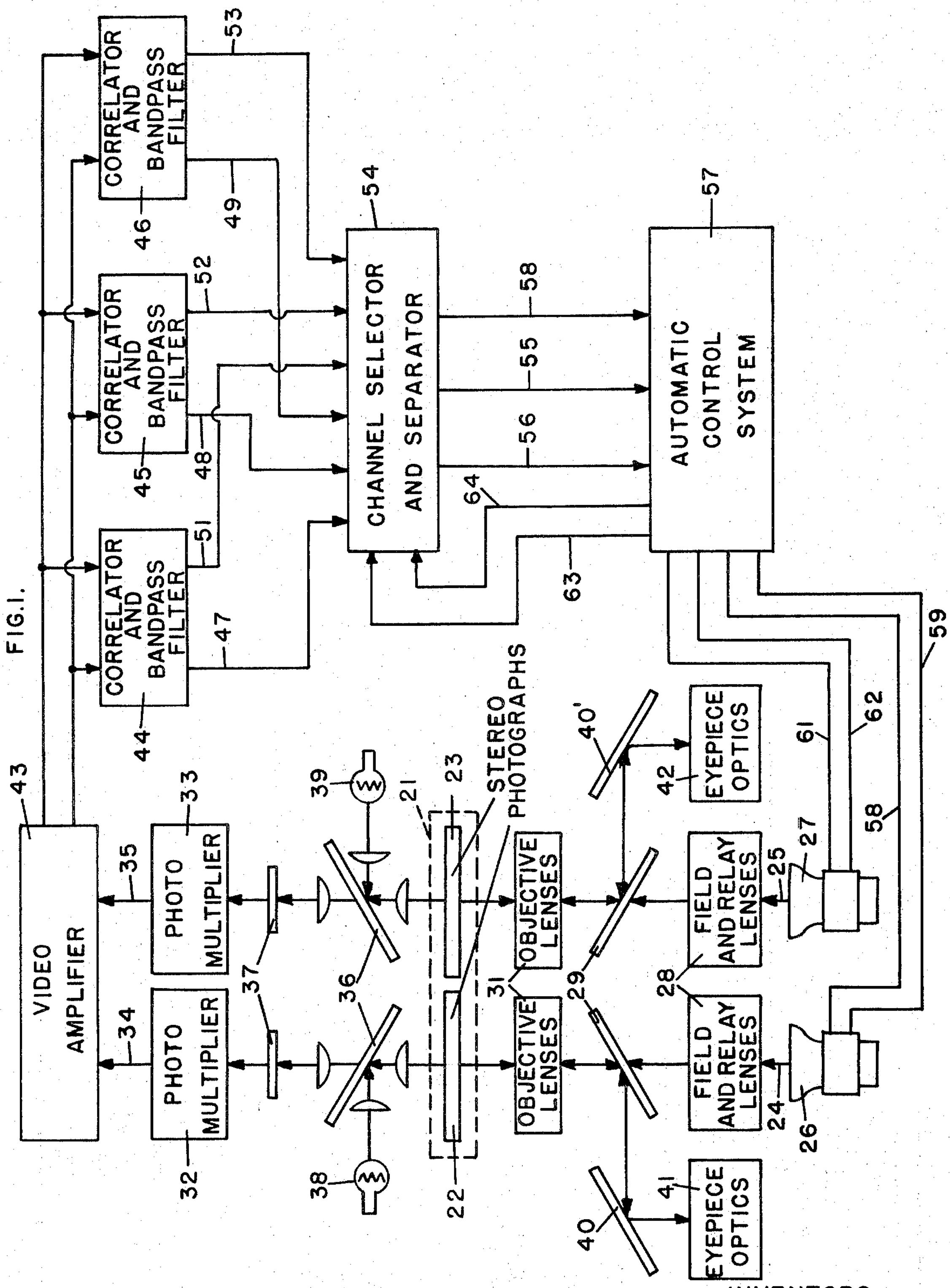


FIG.1.



INVENTORS:
JOHN W. HARDY,
DONALD C. REDPATH,
GILBERT L. HOBROUGH,

BY John E. Toupal
ATTORNEY

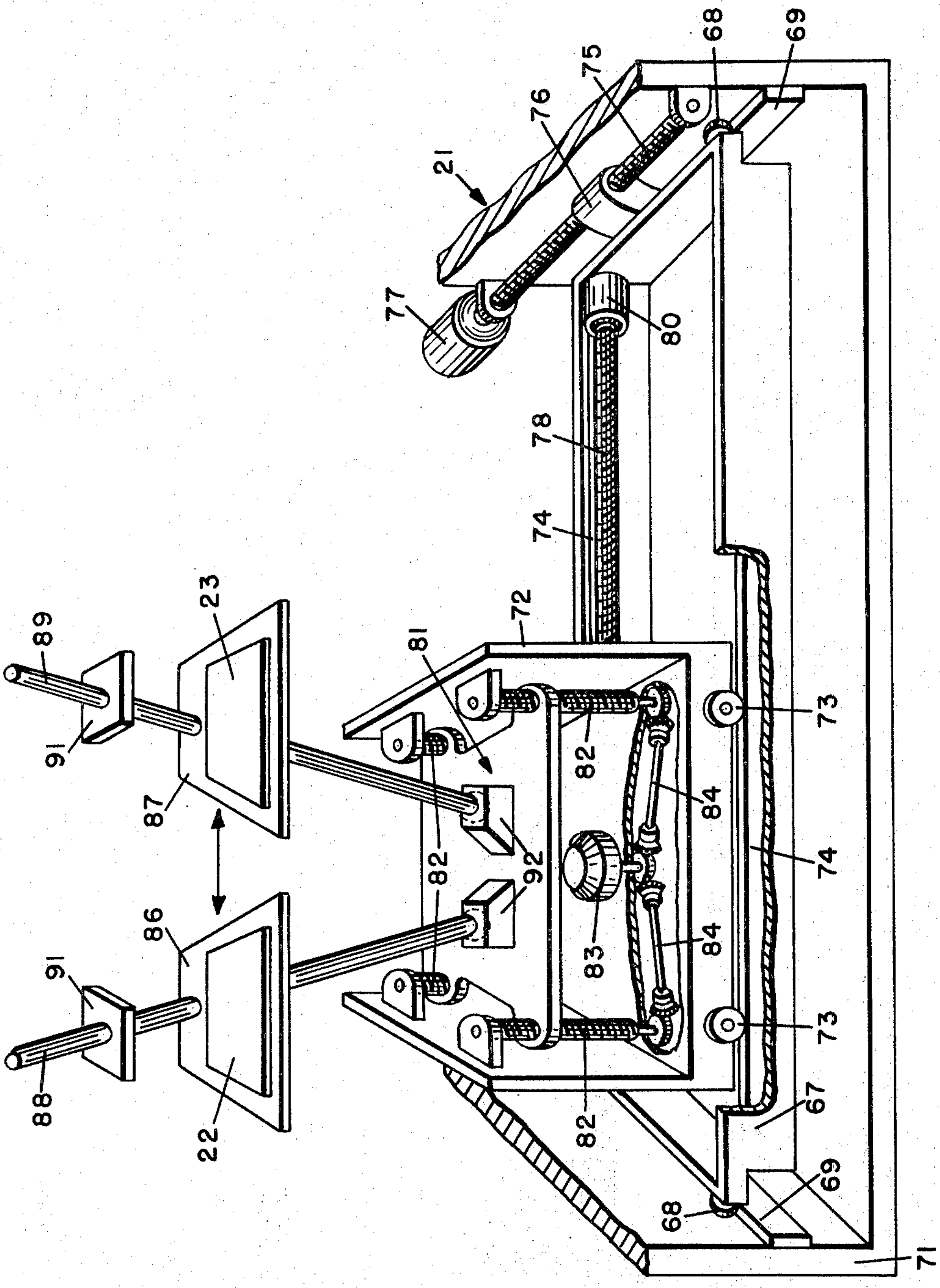


FIG. 2.

INVENTORS:
JOHN W. HARDY,
DONALD C. REDPATH,
GILBERT L. HOBROUGH,

BY John E. Toupal
ATTORNEY

FIG. 5.

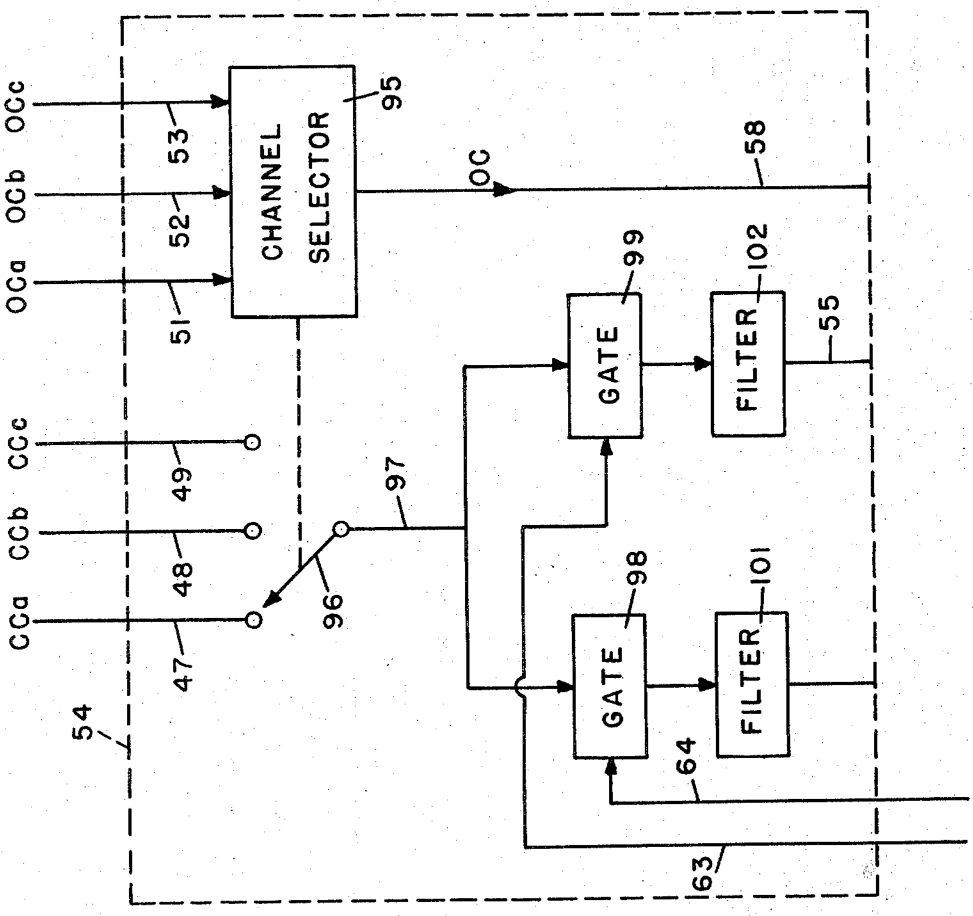


FIG. 3.

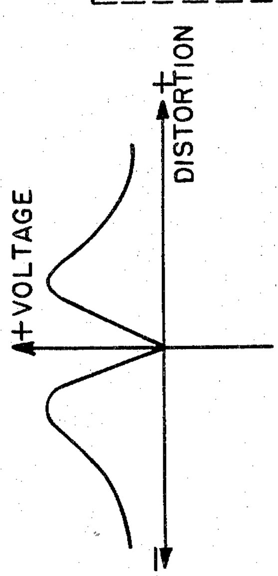
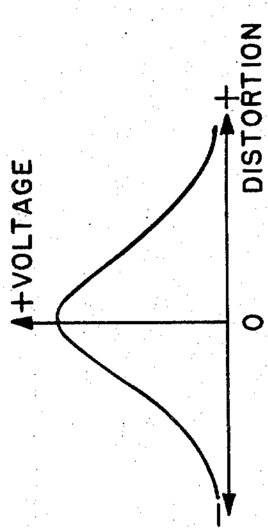


FIG. 4.



INVENTORS:
JOHN W. HARDY,
DONALD C. REDPATH,
GILBERT L. HOBROUGH,

BY John E. Toupal

ATTORNEY

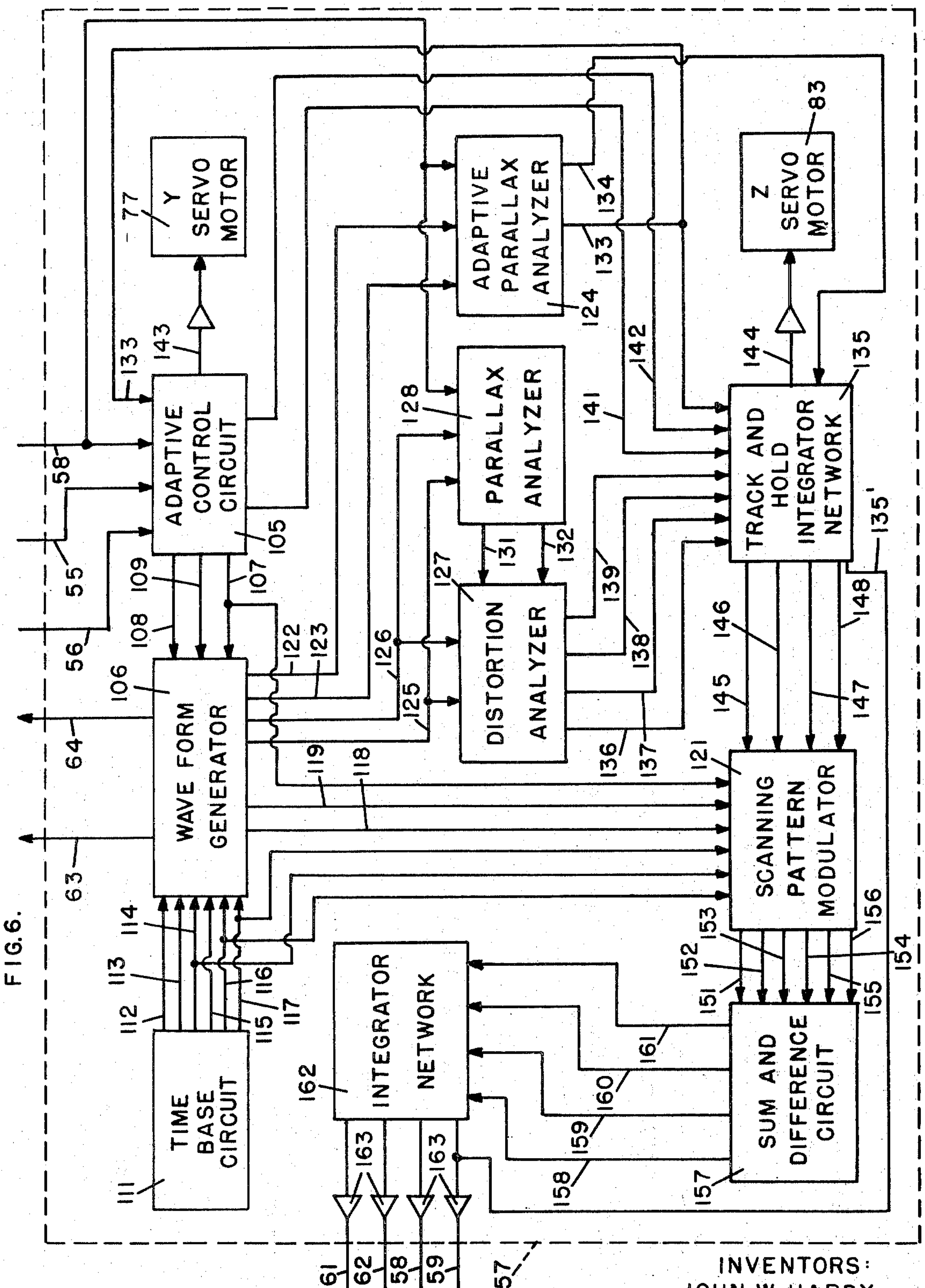


FIG. 6.

INVENTORS:
JOHN W. HARDY,
DONALD C. REDPATH,
GILBERT L. HOBROUGH,

BY John E. Toupal ATTORNEY

FIG. 7.

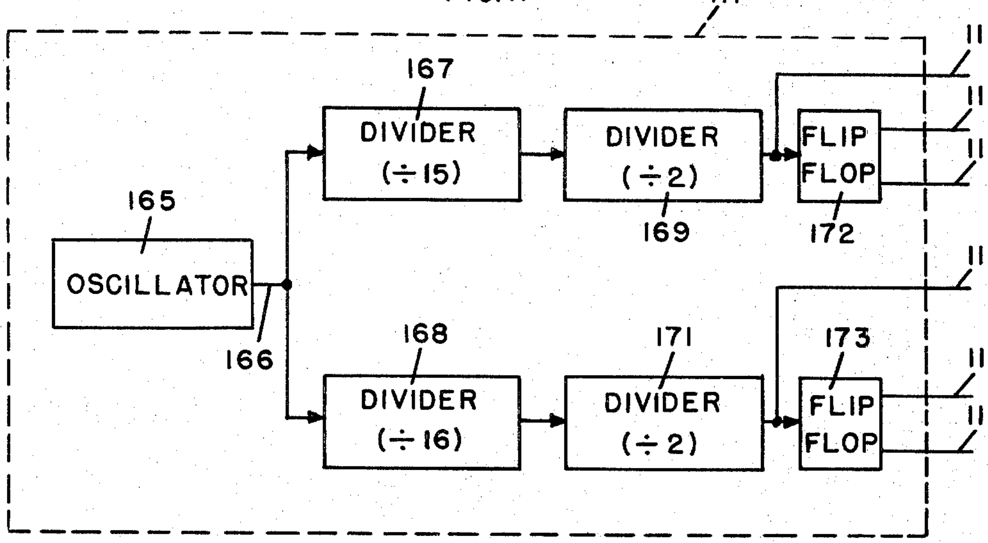


FIG. 14.

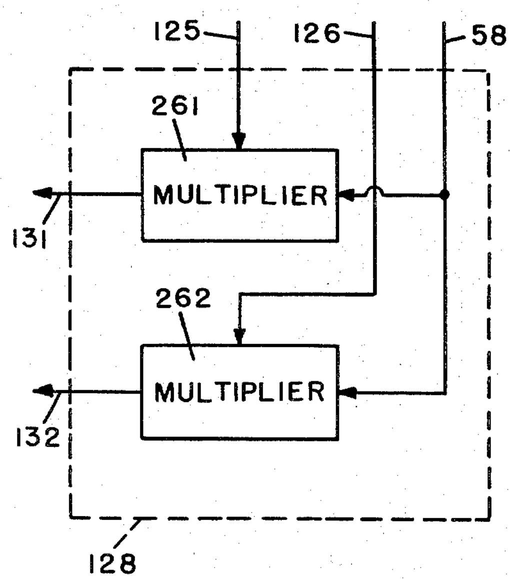
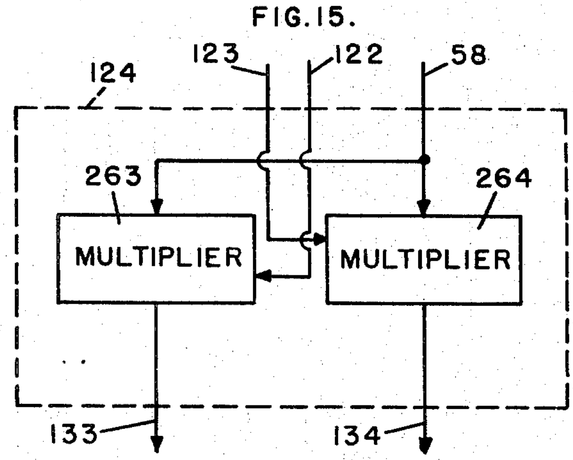


FIG. 15.



INVENTORS:
JOHN W. HARDY,
DONALD C. REDPATH,
GILBERT L. HOBROUGH,
BY John E. Toupal
ATTORNEY

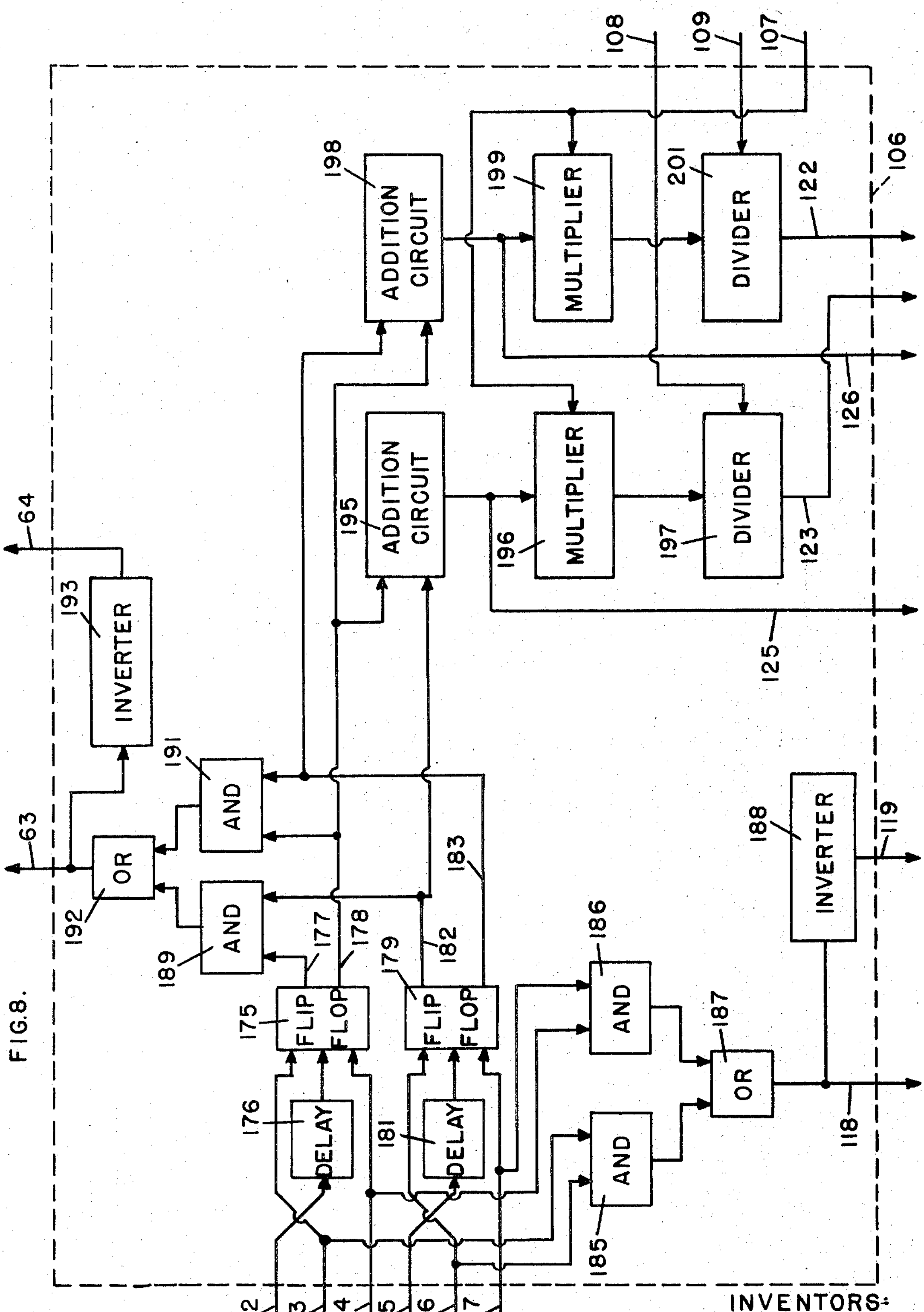
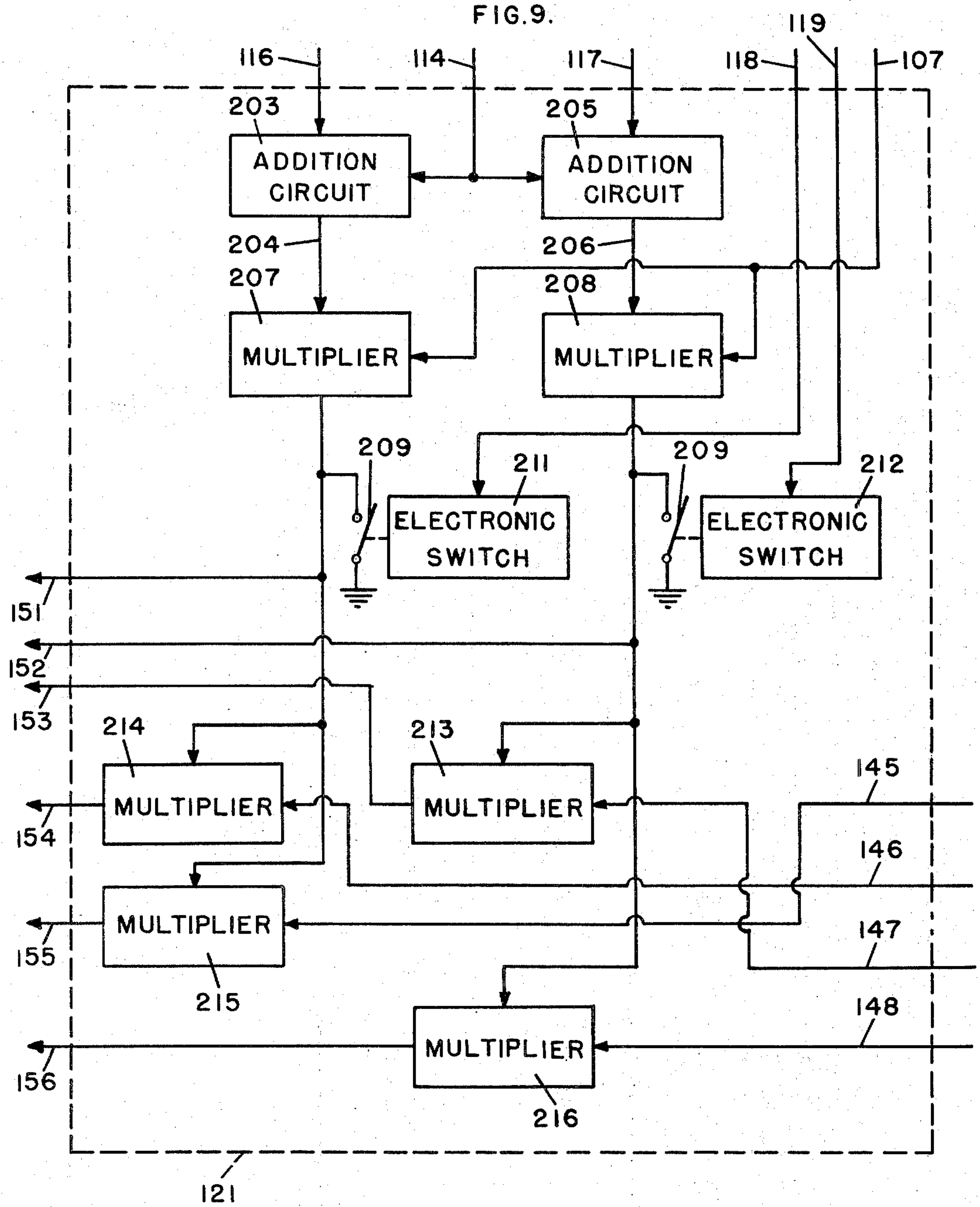


FIG. 8.

INVENTORS:
JOHN W. HARDY,
DONALD C. REDPATH,
GILBERT L. HOBROUGH,

BY John E. Toupal
ATTORNEY

FIG.9.



INVENTORS:
JOHN W. HARDY,
DONALD C. REDPATH,
GILBERT L. HOBROUGH,
BY John E. Toupal
ATTORNEY

FIG. 10.

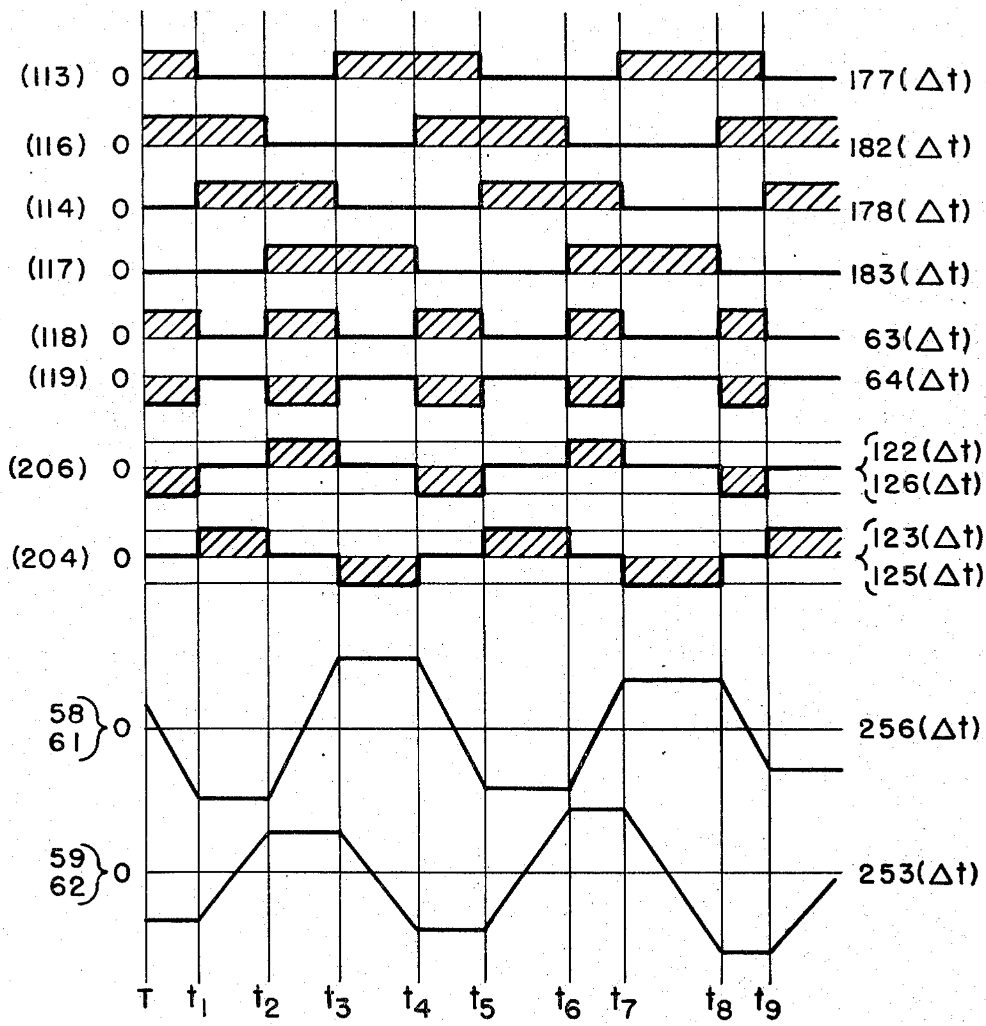
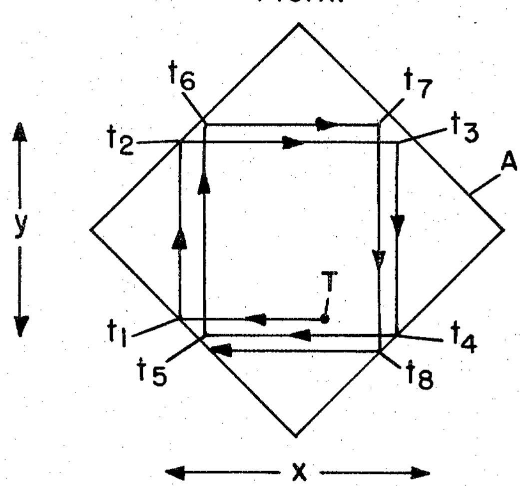


FIG. 11.



INVENTORS:
JOHN W. HARDY,
DONALD C. REDPATH,
GILBERT L. HOBROUGH,

BY John E. Toupal
ATTORNEY

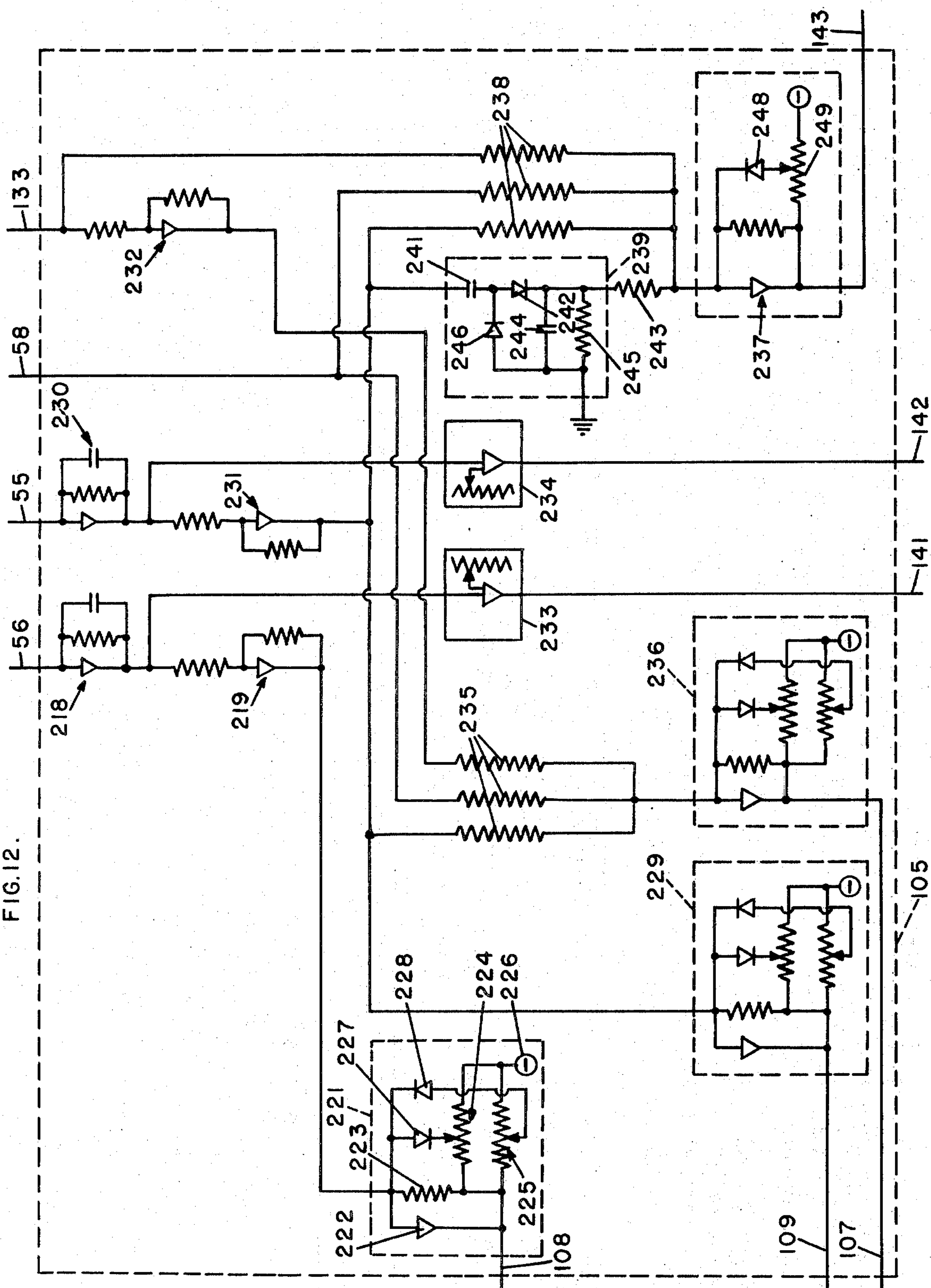
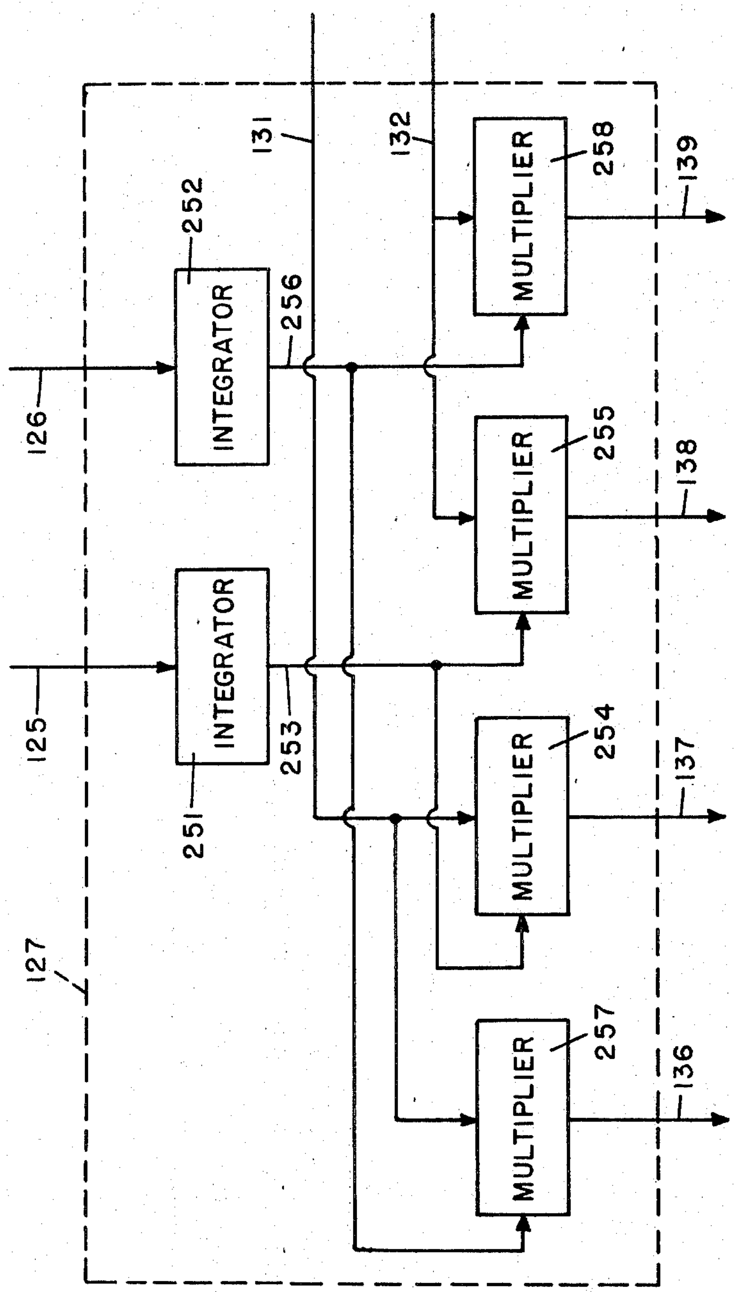


FIG. 12.

INVENTORS:
JOHN W. HARDY,
DONALD C. REDPATH,
GILBERT L. HOBROUGH,

BY John E. Toupal
ATTORNEY

FIG. 13.



INVENTORS:
JOHN W. HARDY,
DONALD C. REDPATH,
GILBERT L. HOBROUGH,

BY John E. Toupal
ATTORNEY

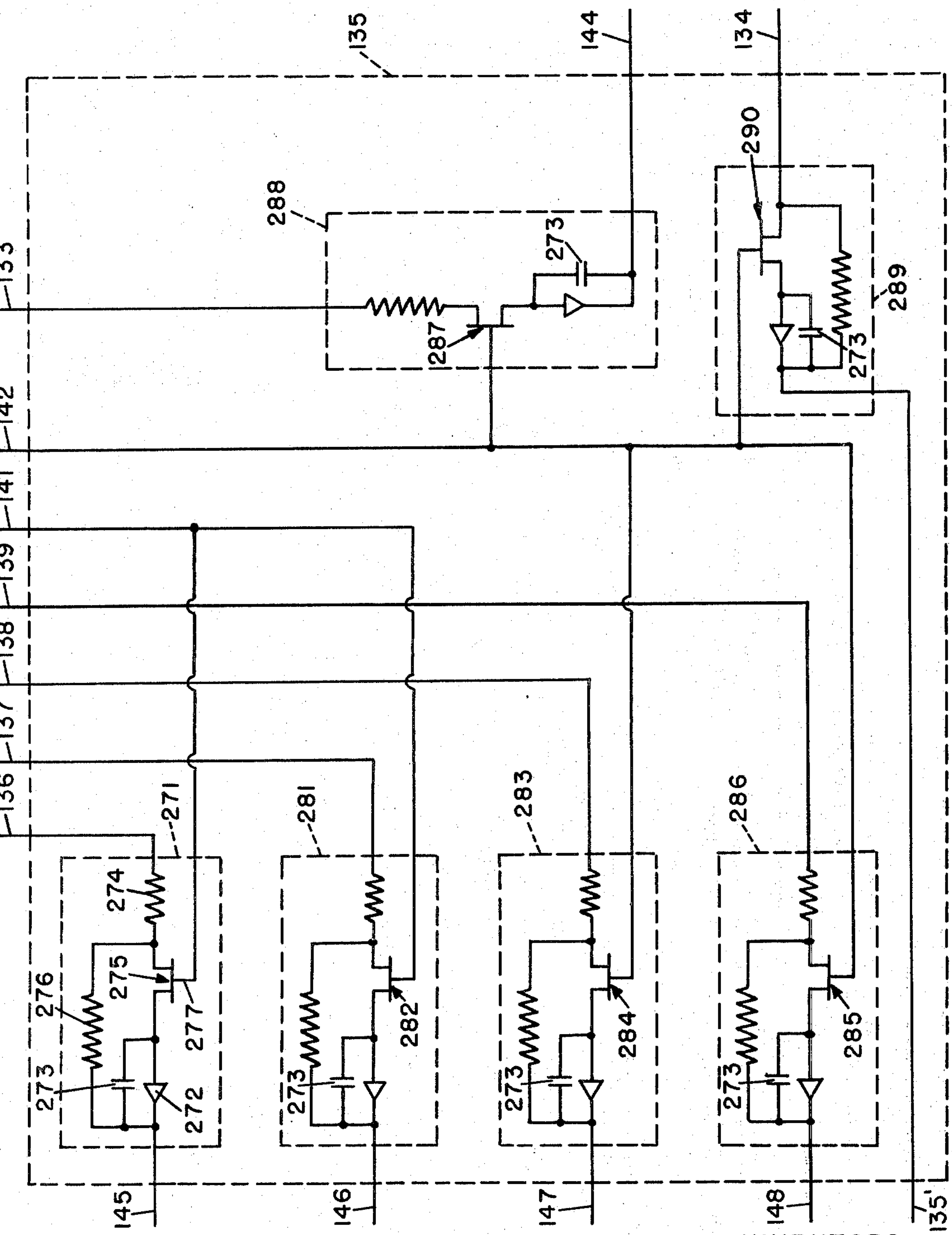
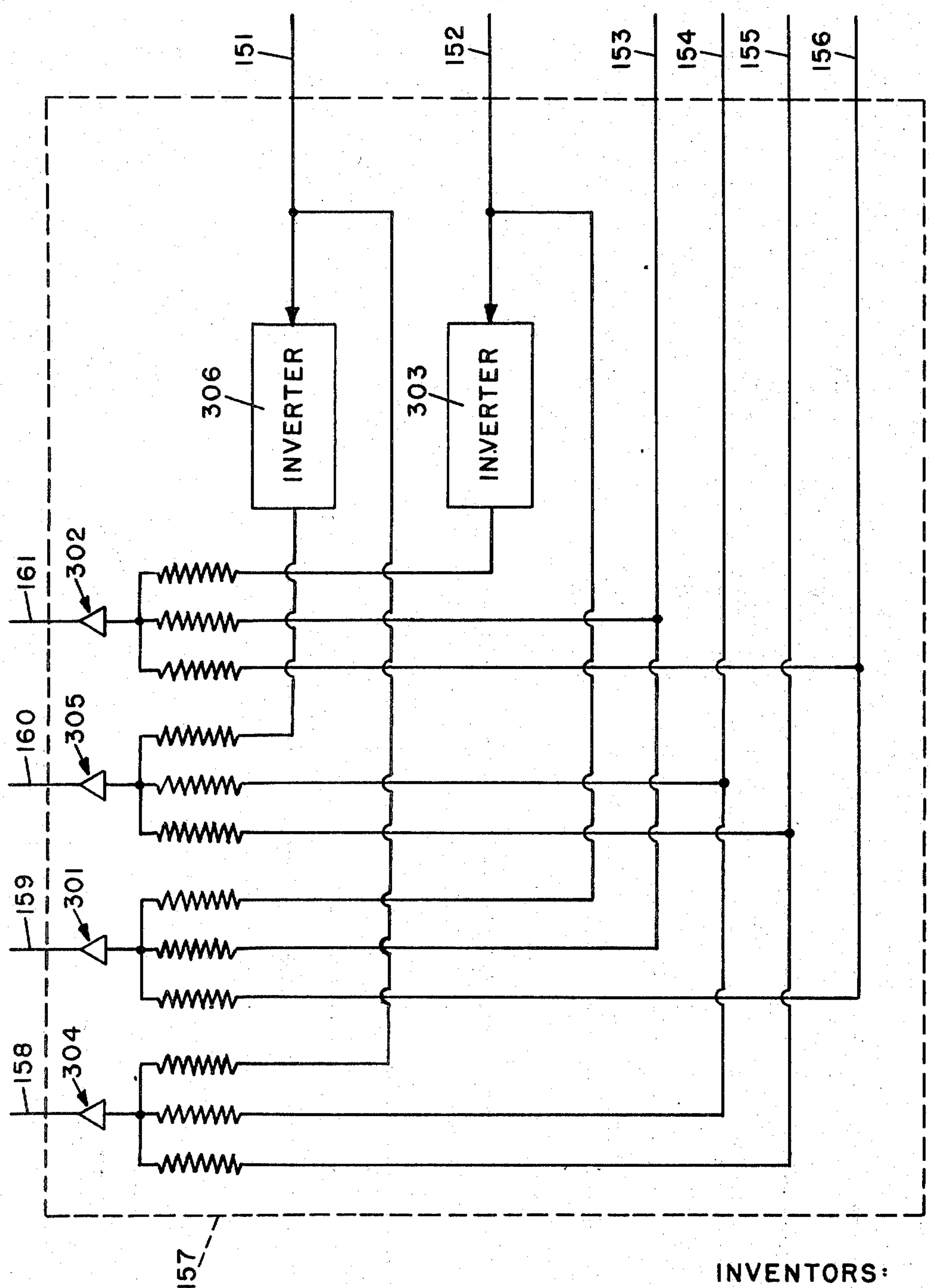


FIG. 16.

INVENTORS:
JOHN W. HARDY
DONALD C. REDPATH,
GILBERT L. HOBROUGH,
BY John E. Toupal
ATTORNEY

FIG. 17.



INVENTORS:
JOHN W. HARDY,
DONALD C. REDPATH,
GILBERT L. HOBROUGH

BY John E. Toupal
ATTORNEY

MULTIPLE IMAGE REGISTRATION SYSTEM

BACKGROUND OF THE INVENTION

This invention relates generally to a dual image registration system and, more particularly, relates to an automatically controlled system of that type.

Although not so limited, the present invention is particularly well suited for use with image registration systems employed during the production of topographic maps. Typically, maps of this type are obtained from stereoscopically related photographs taken from airplanes. When the photographs are accurately positioned in locations corresponding to the relative positions in which they were taken, their projection upon a suitable base produces a three-dimensional presentation of the particular terrain imaged on the photographs. However, a coherent stereo presentation is obtained only if the photographs are properly registered, i.e. so positioned that homologous areas in the two projections are aligned and have the same orientation. The problem of image registration is accentuated by the fact that image detail in the photographs typically is not identical in all respects. Such detail non-uniformity is caused, for example, by photographing a scene from different camera viewpoints or by variations in altitude, roll and pitch of the photographic aircraft. The resultant distortion between corresponding areas in the photographs prevents common detail registration when the images retained by both photographs are projected onto a common viewing plane.

A number of systems have been developed for simplifying the registration of dual images. Basically, most such registration systems scan homologous areas in the two images and convert the scanned graphic data into a pair of electrical video signals. By various correlation and analyzation techniques, the video signals are used to produce error signals representing certain types of distortion existing between the scanned images. The scanned areas are then rendered congruent by a transformation mechanism that induces appropriate relative movement and scanning pattern shape adjustment therebetween in response to the derived error signals.

In a typical stereo plotting instrument the similar images retained thereon are analyzed with respect to x and y coordinate axes. Relative image displacement along the axis corresponding to the direction of separation between the positions from which the stereo photographs were taken, commonly called x-parallax is corrected, for example, by a servomechanism that produces appropriate relative movement between the stereo plates or by height adjustment of a viewing surface which intercepts a projection of the images. The magnitude of required x-parallax correction is directly related to relative elevation of the terrain photographed and provides the contour information necessary for topographic maps. Scale distortion along the other coordinate axis, commonly known as y-parallax, and other first and higher order distortions also are corrected in systems providing a visual presentation of the stereo model. These latter types of distortion are corrected, for example, by producing relative changes in the rasters of the scanning devices utilized, by controlling optical devices used for projection of the images, or introducing appropriate relative movement between the stereographic plates. The entire stereo model represented by a single pair of stereographic plates is normally examined by traversing scanning patterns back and forth across the photographs along paths corresponding to the y-coordinate direction and incrementally spaced apart in the x-coordinate direction. Typical stereo plotting instruments of this type are disclosed, for example, in U.S. Pat. No. 2,964,644 issued on Dec. 13, 1960 to Gilbert Louis Hobrough and in U.S. Pat. No. 3,145,303 issued on Aug. 18, 1964, to the same inventor.

An important problem associated with stereo plotters results from variations in the level of correlation quality experienced during a plotting operation. All aerial photographs have a structure and spatial frequency content that differs from point to point. For this reason the level of information available for correlation is continually varying as the plates are traversed. Various parameters of the correlation process must be correspondingly varied, therefore, if optimum results are to be obtained. For example, although registration accuracy is enhanced by reducing the size of the scanning rasters utilized, the acceptable minimum raster size is determined by correlation quality which is variably dependent upon correlatable image content. Thus, a larger raster size is desired during periods of poor correlation caused either by relative photo displacement or by dissimilar image detail information produced in photographs of rough terrain. An increase in raster size also is desired when scanning photographic images retaining a low level of variable image detail. Similarly, although rapid traversals of the stereo models are desirable in the interest of reduced processing time, the traversal velocity should be reduced during periods requiring large x-parallax correction so as to accommodate the inherent reaction time of the servomechanism producing that correction. It is desirable also to reduce traversing velocity when scanning areas of low information content because the correspondingly low values of the resultant error signals limit the rate at which servo corrections can be made.

Another system parameter that is undesirably subject to the type of image detail being scanned is the gain of the servosystem used for controlling x-parallax correction. To simplify servo system design, it is desirable that electrical circuit gain be maintained substantially constant. However, gain, which is dependent upon the slope of the raw error signal derived from the video signals, is affected by both the size of the scanning pattern utilized and the level of inherent image detail in the scanned areas.

Previous systems such as those disclosed in the above noted patents have utilized a cross-correlation signal indicative of correlation quality to control certain system parameters including scanning pattern size and traversal velocity. Also known is the control of scanning raster size with signals derived from the x-parallax error signal and representative of such factors are terrain roughness and slope. However, the control functions provided by prior image registration systems have not proven fully satisfactory and various deficiencies still exist.

The object of this invention, therefore, is to provide an improved multiple image registration instrument with an automatic control system that alleviates the problems mentioned above.

CHARACTERIZATION OF THE INVENTION

The invention is characterized by the provision of a multiple image registration system comprising electronic scanners for directing scanning patterns onto corresponding areas in a pair of similar images and a signal generator for producing a first analog signal representing variable detail along the path scanned in one of the images and a second analog signal representing variable detail along the path scanned in the other image. The analog signals are correlated to produce an orthogonal correlation signal having an amplitude proportional to the degree of relative image detail misregistration along the scanned paths and used to derive error signals that correct the misregistration. Also produced is a cross-correlation signal having an amplitude proportional to the level of correlatable image detail along the scanned paths. Raster signals that generate continuous scanning paths formed by alternating orthogonally related path segments are formed by a waveform generator that also provides a reference signal that indicates which of the orthogonally related sets of path segments are being scanned. By gating of the cross-correlation signal with the reference signal, an *x*-cross-correlation component is derived proportional to correlatable information present along only one of the orthogonal path sets. The unique correlation quality information present in the *x*-cross-correlation component permits a control circuit to effect various types of directly pertinent control functions.

According to one feature of the invention, the *x*-cross-correlation component is utilized to vary the size of the areas scanned by the electronic scanners. The scanning pattern size is increased in response to an indication of poor correlation so as to help maintain the registration system within its operable limits. Poor correlation can result, for example, because of relative displacement between the compared images or, in the case of typical stereo photographs used in map making, because of dissimilar detail present in images of rough terrain. The scanning area size also is increased to enhance corrective signal output levels during periods wherein the information retained by the compared images is inherently low.

According to a featured embodiment of the invention, the image registration system is of the type generally used for the production of topographic maps and includes a *z*-servo system that corrects *x*-parallax by producing relative rectilinear movement between the compared images in a direction parallel to one of the orthogonally related sets of scanning paths. The measured magnitude of this relative movement required to eliminate *x*-parallax is, of course, indicative of the elevation of the terrain imaged on a pair of stereo photographs.

According to another feature of the invention, the system includes a traversing mechanism that continuously changes the corresponding scanned areas by producing relative movement between the images and the scanning patterns in directions orthogonally related to the relative image movement produced to correct *x*-parallax. The velocity of this scanning pattern traversal is varied by the control circuit also in response to the value of the *x*-cross correlation component. The traversing speed is lowered to reduce the rate at which servo corrections must be made during periods of low correlatable detail in the *x*-parallax direction that result in low values of the *x*-parallax corrective error signals.

Another feature of the invention is the provision of a holding circuit that prevents the *z*-servo mechanism from producing further *x*-parallax corrective action in response to a predetermined condition indicated by the *x*-cross-correlation component. Corrective action is stopped when the absence of a given minimum quality of correlation is indicated by the value of the *x*-cross-correlation component. This prevents uncontrolled action that could produce complete failure of the registration system. Corrective action is automatically reestablished when *x*-direction correlation quality is sufficiently improved as indicated by the value of the *x*-cross-correlation component.

According to another feature of the invention, the loop gain of the *x*-servo mechanism also is varied in response to the value of the *x*-cross-correlation component. By increasing the loop gain during periods of low correlatable image detail, a more uniform gain characteristic is obtained thereby simplifying the design of the servo system itself.

According to still another feature of the invention, the control circuit also varies the gain of the *z*-servo loop in response to changes in the size of the areas scanned in the compared images. Since the value of loop gain is dependent upon the size of the areas scanned, this feature also facilitates the maintenance of a substantially uniform loop gain thereby simplifying circuit design.

Another feature of the invention effects size variations of the scanned areas in response to the value of the orthogonal correlation signal. The scanned areas are reduced in size in response to a low orthogonal correlation signal value thereby increasing the accuracy of the registration system.

According to another feature of the invention, the reference signals generated by the waveform generator are used also to derive from the cross-correlation signal a *y*-component during periods of scan along the other set of scanning path segments. The *y*-cross-correlation component provides unique correlation quality information associated with image detail scanned in only directions corresponding to the other path sets.

Another feature of the invention is the provision of a dual image registration system of the above types including a closed loop *y*-parallax transformation system for producing relative changes in the scanned areas by displacing the scanning pattern produced on at least one of the compared images. Changes are made in response to a *y*-parallax error signal derived from the orthogonal correlation signal. The loop gain of the *y*-parallax transformation system is varied in response to the *y* cross-correlation component thereby improving loop gain uniformity and simplifying circuit design.

According to still another feature of the invention the holding circuit also prevents the *y*-parallax transformation system from producing further relative scanning pattern changes in response to a given condition indicated by the *y* cross-correlation component. As in the case of *x*-parallax correction, this prevents uncontrolled action that could produce complete failure of the registration system. Again corrective action is automatically reestablished when *y*-direction correlation quality is sufficiently improved as indicated by the value of the *y*-cross-correlation component.

The invention is characterized further by the provision of an image registration system of the above featured types wherein the raster signals provided by the waveform generator are substantially triangular signals of frequencies f_1 and f_2 that produce the orthogonally related scanning path segment sets and wherein f_1/f_2 expressed in its lowest terms is p/q where p and q are integers and $(p + q)$ is less than 100. By limiting the number of lines in the scanning pattern, a desirable high frame rate can be achieved. In addition, a larger scanning spot can be utilized for a given size scanning raster thereby providing more light for generation of the video signals. Finally, since the object of the invention is to generate transformation error signals rather than to provide a picture, the reduced number of lines is not objectionable.

DESCRIPTION OF THE DRAWINGS

These and other objects and features of the invention will become more apparent upon a perusal of the following specification taken in conjunction with the accompanying drawings wherein:

FIG. 1 is a general block diagram illustrating the functional relationship of the main components of the apparatus;

FIG. 2 is a perspective schematic view of the image transformation mechanism 21 shown in FIG. 1;

FIG. 3 is a graph illustrating the voltage vs. distortion characteristic of a rectified raw orthogonal correlation signal generated in the system of FIG. 1;

FIG. 4 is a graph illustrating the voltage vs. distortion characteristic of a cross-correlation signal produced by the system of FIG. 1;

FIG. 5 is a block diagram illustrating the channel selector and separator shown in FIG. 1;

FIG. 6 is a block diagram illustrating the automatic control system shown in FIG. 1;

FIG. 7 is a block diagram illustrating the time base circuit shown in FIG. 6;

FIG. 8 is a block diagram illustrating the waveform generator shown in FIG. 6;

FIG. 9 is a block diagram illustrating the scanning pattern modulator shown in FIG. 6;

FIG. 10 is a graph showing a plurality of voltage waveforms plotted against time;

FIG. 11 is a diagrammatic view illustrating the character of the path followed by the spot of a cathode ray tube in tracing a scanning pattern according to the invention;

FIG. 12 is a block diagram illustrating the adaptive control circuit shown in FIG. 6;

FIG. 13 is a block diagram illustrating the distortion analyzer shown in FIG. 6;

FIG. 14 is a block diagram illustrating the parallax analyzer shown in FIG. 6;

FIG. 15 is a block diagram illustrating the adaptive parallax analyzer shown in FIG. 6;

FIG. 16 is a block diagram illustrating the track and hold integrator network shown in FIG. 6; and

FIG. 17 is a schematic diagram of the sum and difference circuit shown in FIG. 6.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIG. 1 there is shown in block diagram form an image transformation mechanism 21 retaining a pair of stereo photographic transparencies 22 and 23. Scanning beams 24 and 25 produced by, respectively, cathode ray tubes 26 and 27 are directed toward the transparencies 22 and 23 by field and relay lens assemblies 28, dichroic beam splitters 29 and objective lenses 31. After passing through the transparencies 22 and 23 the scanning beams 24 and 25 are received by photomultipliers 32 and 33 that produce on lines 34 and 35, respectively, video analog signals representing the variable detail retained by the photographs. Between the transparencies 22 and 23 and the photomultipliers 32 and 33 the scanning beams pass through lens systems including dichroic mirrors 36 and blue light filters 37.

Also reflected through the transparencies 22 and 23 by the dichroic mirrors 36 is yellow light produced by light sources 38 and 39. After being modulated by the transparencies 22 and 23, the yellow light is directed to a pair of eyepiece optical assemblies 41 and 42 by the objective lenses 31, the dichroic beam splitters 29 and a pair of mirrors 40 and 40'. The eyepiece optical assemblies 41 and 42 provide for a viewer in conventional manner a stereo presentation of the image detail retained by the transparencies 22 and 23.

After amplification in a video amplifier 43 both of the analog signals on lines 34 and 35 are fed into each of three correlator and bandpass filter circuits 44, 45 and 46 that separate the signals into bands A, B and C. The circuits 44, 45 and 46 also correlate the video signals producing on lines 47, 48 and 49, cross-correlation signals proportional to the level of correlatable image detail being scanned in the photographs 22 and 23 and produce on lines 51, 52 and 53, orthogonal correlation signals proportional to the degree of relative image detail misregistration existing between the scanned paths. The correlator and bandpass filters 44, 45 and 46 are conventional and do not, per se, form a part of this invention. Suitable circuits of this type are disclosed, for example, in the above noted U.S. Pat. Nos. 2,964,644 and 3,145,303.

The correlation signals on lines 47–53 are fed into a channel selector and separator network 54 that is described in greater detail below. This network 54 separates a cross-correlation signal selected from one of the lines 47, 48 and 49 into x and y cross-correlation components that are fed on lines 55 and 56, respectively, into an automatic control system 57. Also received by the control system 57 on signal line 58 is the orthogonal correlation signal selected from line 51, 52 or 53. The control system 57, which is described in greater detail below, produces on lines 58 and 59 output signals that are applied to the deflection coils of cathode ray tube 26 and on lines 61 and 62 signals that are applied to deflection coils of cathode ray tube 27. Also provided by the control system 57 on lines 63 and 64 are reference signals that are applied to the channel selector and separator network 54.

Shown in FIG. 2 is a schematic perspective view of the dual image transformation system 21 shown in FIG. 1. The transformation system 21 provides controlled movement of the photographic transparencies 22 and 23 in orthogonally related x and y-coordinate directions. A y-carriage 67 is mounted on rollers 68 for movement along parallel y-tracks 69 supported by a frame 71. Similarly, an x-carriage 72 is mounted on rollers 73 for movement along x-tracks 74 supported by the y-carriage 67. Movement of the y-carriage 67 is produced by rotation of a y-lead screw 75 that engages the internally threaded collar 76. Rotation of the lead screw 75 is controlled by a y-servo motor 77. Similarly, movement of the x-carriage 72 along tracks 74 is produced by rotation of an x-lead screw **78** also driven by a suitable x-servo motor **80**.

A z-carriage **81** is mounted for vertical movement on z-lead screws **82** supported by the x-carriage **72**. Controlled vertical movement of the z-carriage **81** is produced by z-servo motor **83** coupled to the z-lead screws **82** by drive shaft and bevel gear assemblies **84**. The photographic transparencies **22** and **23** are mounted, respectively, in photo carriages **86** and **87**. Slidably engaging the photo carriages **86** and **87** and providing mechanical coupling thereof to the z-carriage **81** are space rods **88** and **89**. Opposite ends of the space rods **88** and **89** terminate, respectively, in pivot connections **91** and ball joint assemblies **92** mounted on the z-carriage **81**. The connections **91** and **92** permit oppositely directed arcuate movement of rods **88** and **89** in response to vertical movement of the z-carriage **81**. This in turn produces relative rectilinear motion between the transparencies **22** and **23** in the x-coordinate direction defined by x-rails **74** and of a sense determined by the direction of z-carriage **81** movement. The image transformation mechanism **21** is a conventional unit marketed under the trade name Planimat by the Carl Zeiss Company, of Oberkochen, Wurttemburg, Germany. The device is also related to similar transformation systems disclosed in the above noted U.S. Pat. Nos. 2,964,644 and 3,145,303.

In response to appropriate energization of y-motor **77** the photo transparencies **22** and **23** move simultaneously with the y-carriage **67** in either a plus or minus y-coordinate direction defined by y-tracks **69**. Similarly, energization of x-lead screw **78** produces simultaneous movement of the transparencies in either a plus or minus x-direction defined by the x-tracks **74**. Thus, the mechanism **21** provides selective synchronized two dimensional movement of the transparencies **22** and **23** relative to their respective scanning beams **24** and **25** illustrated in FIG. **1**. Conversely, vertical movement of the z-carriage **81** in response to energization of z-motor **83** results in relative movement between the transparencies **22** and **23** and the scanning beams **24** and **25** as well as between the transparencies themselves. As is well known in the map making field, this relative motion between the transparencies **22** and **23** corrects parallax exsiting between scanned areas thereof. The relative elevation of the z-carriage **81** required to eliminate this parallax is directly related to the elevation of the terrain imaged on the stereo photos.

In typical operation, the system shown in FIG. **1** is used to profile a stereo model represented by the stereographic transparencies **22** and **23**. For example, to profile automatically in the y-coordinate direction, y-motor **77** is driven at a predetermined velocity giving rectilinear motion to y-carriage **67** and the transparencies **22** and **23** relative to the scanning beams **24** and **25**. The x-motor **80** forms a part of a positioning servo, that holds the x-carriage **72** rigidly in the x-coordinate direction. The system is thereby constrained to trace out a straight profile in the y-direction and the x-position is selected by an automatic stepping system (not shown) controlled, for example, by a conventional limit switch operated when the y-carriage **67** reaches one edge of the stereo model. In response to actuation of the limit switch, the direction of rotation of y-motor **77** also would be reversed to thereby reverse the traversal direction of the y-carriage **67**. Obviously, a reversal in roles of the x and y-motors would result in the tracing of profiles in the x-direction. As a profile is being traced, the z-motor **83** is energized as described below by an x-parallax error signal that produces vertical movement of the z-carriage **81**. This adjusts the relative positions of transparencies **22** and **23** in the x-direction to eliminate x-parallax and thereby provide a direct indication of terrain elevation. Simultaneously, y-parallax and other first order distortions are corrected in response to other error signals produced by the control system **57** on lines **58, 59, 61** and **62**. Consequently, a viewer utilizing the eyepiece optics **41** and **42** is provided with a corrected stereo presentation of the image scene retained by the transparencies **22** and **23**. The correction of y-parallax and other distortions can be achieved in various ways. However, a preferred method involves controlled relative distortion of the cathode ray tube rasters as disclosed in U.S. Pat. No. 3,432,674 of Gilbert L. Hobrough issued Mar. 11, 1969.

FIG. **3** illustrates the voltage vs. distortion characteristic of the rectified raw orthogonal correlation signals derived by the correlators **44, 45** and **46** on, respectively, signal lines **51, 52** and **53**. As shown, the signals have a zero value when the video signals on line **34** and **35** indicate no relative distortion, i.e., when the scanning beams **24** and **25** (FIG. **1**) are simultaneously scanning exactly homologous image detail in the photographic transparencies **22** and **23**. Conversely, increasing degrees of relative image detail misregistration within the detection range of the system results in increasing values of the raw orthogonal correlation signal. This signal is obtained, for example, by multiplication and subsequent rectification of the analog signals on lines **34** and **35** after introducing a predetermined phase shift therebetween. Thus, the orthogonal correlation signal has an amplitude proportional to the degree of relative image detail misregistration of either sense along the paths scanned in the transparencies **22** and **23** by the scanning beams **24** and **25**.

FIG. **4** illustrates the voltage vs. distortion characteristic of the cross-correlation signals generated by the correlators **44, 45** and **46** on, respectively, signal lines **47, 48** and **49**. As shown, the cross-correlation signal has a maximum value for zero distortion corresponding to good image detail correlation and decreasing signal values for increasing degrees of distortion of either sense. The amplitude of the cross-correlation signal is also dependent upon the inherent quantity of homologous and detectable image detail present along the scanned paths. Thus, a high cross-correlation signal value indicates a high level of correlatable image detail along the simultaneously scanned paths and a low signal value indicates the contrary.

Various types of correlator circuits are known for producing the above mentioned rectified raw orthogonal correlation and cross-correlation signals. Therefore, a detailed description of correlators **44, 45** and **46** is believed unnecessary. Likewise, bandpass filters for separating the signals into separate frequency bands are conventional and deemed to require no further explanation. Examples of circuits suitable for these functions are disclosed in the above noted U.S. Pat. Nos. 2,964,644, 3,145,303 and 3,432,674.

FIG. **5** shows in block circuit form the channel selector and separator circuit **54** shown in FIG. **1**. The raw orthogonal correlation signals on lines **51, 52** and **53** are fed into a channel selector circuit **95** that automatically selects one of the signals for transmission on output line **58**. Selection is based upon the degree of correlation existing between the images with higher frequency channels selected as image correlation improves. The channel selector **95** does not, per se, form a part of the present invention and consequently will not be described in further detail. However, a channel selector suitable for this application is disclosed in U.S. Pat. No. 3,513,257 of Gilbert L. Hobrough, issued May 19, 1970 and assigned to the assignee of the present application.

Also controlled by the channel selector **95** is a switch **96** that connects line **97** to one of the input lines **47, 48** or **49** carrying the cross-correlation signal corresponding to the selected orthogonal correlation signal transmitted to output line **58**. The selected cross-correlation signal output on line **97** is fed into gates **98** and **99** that are gated, respectively, by reference signals on lines **64** and **63** described in greater detail below. After being filtered in filtered circuits **101** and **102** the outputs of gates **98** and **99** appear, respectively, on lines **56** and **55**.

FIG. **6** illustrates in block circuit form the automatic control system **57** shown in FIG. **1**. Receiving the cross-correlation signals from the channel selector **54** on lines **55** and **56** is an adaptive control circuit **105** that feeds control signals to waveform generator **106** on signal lines **107, 108** and **109**. Also received by the waveform generator **106** from a time base circuit **111** are reference signals on lines **112–117**. Signals produced by the waveform generator **106** on output lines **118** and **119** are fed into a scanning pattern modulator **121** that also receives from the time base circuit **111** the reference signals on lines **114, 116** and **117**, and from the adaptive control circuit **105** the control signal on line **107**. Additional outputs of the waveform generator **106** on lines **122** and **123** are applied to an adaptive parallax analyzer **124** that also receives the selected orthogonal correlation signal on input line **58**. Still other outputs of the waveform generator **106** on lines **125** and **126** are fed into both a distortion analyzer **127** and a parallax analyzer **128**, the latter of which also receives the orthogonal correlation signal on input line **58**.

Parallax error signals produced by the parallax analyzer **128** are transmitted into the distortion analyzer **127** on lines **131** and **132**. Similar parallax error signals are produced by the adaptive parallax analyzer **124** on line **133** and **134**. The x-parallax signal on line **133** is fed back into the adaptive control circuit **105** and also into a track and hold integrator network **135**. The y-parallax error signal on line **134** is controlled in track and hold integrator network **135** producing an output signal on line **135**. Received by the track and hold integrator network **135** on lines **136–139** are first order distortion error signals from the distortion analyzer **127**. Also received by the track and hold integrator **135** on lines **141** and **142** are control signals from the adaptive control circuit **105** that produces on line **143** a servo control voltage for the y-servo motor **77** also shown in FIG. **2**. An x-parallax error voltage output of the track and hold integrator **135** on line **144** is used as a control voltage for the z-servo motor **83** also shown in FIG. **2**. The signals from track and hold integrator **135** on lines **145–148** are applied to the scanning pattern modulator **121** that produces output signals on lines **151–156**. These signals are algebraically summed in a sum and

difference circuit **157** to provide raster control signals on lines **158–161** that are integrated in the integrator network **162**. Outputs of the integrator network **162** are amplified by amplifiers **163** producing deflection coil input signals on lines **58, 59, 61** and **62**.

FIG. **7** shows the time base circuit **111** shown in FIG. **6**. An oscillator **165** produces on line **166** a pulsed output the frequency of which is reduced by a factor of **15** in a divider **167** and by a factor of **16** in a divider **168**. The output of divider **167** is fed into divider **169** producing on line **112** an output with a pulse frequency reduced by a factor of **2**. Similarly, the output of divider **168** is applied to divider **171** that produces on line **115** an output with a pulse frequency reduced by a factor of 2. Receiving the output of divider **169** is a flip flop **172** that produces complementary square wave signals on lines **113** and **114**. In the same manner, a flip flop **173** is triggered by the output of divider **171** to produce complementary square wave signals on lines **116** and **117**.

FIG. **8** illustrates in block circuit form the waveform generator **106** shown in FIG. **6**. Received by a flip flop **175** are signals on lines **113** and **114** in addition to the signal on line **112** after delay in a delay circuit **176**. The flip flop **175** is triggered by the delayed output of delay circuit **176** to produce on lines **177** and **178** complementary square wave signals, the relative phase relationshp of which is determined by the polarities of the signals on lines **113** and **114**. Correspondingly, a flip flop **179** receives the signals on lines **116** and **117** in addition to the signal on line **115** after delay in a delay circuit **181**. The outputs of flip flop **179** on lines **182** and **183** also are complementary square wave signals triggered by the delayed output of delay circuit **181** and having relative phase relationships determined by the polarity of the signals on lines **116** and **117**.

Signals on lines **113** and **116** also are applied to an AND gate **185** and those on lines **114** and **117** to an AND gate **186**. Receiving the outputs of AND gates **185** and **186** is an OR gate **187** that produces a reference output signal on line **118**. A complementary reference signal is produced on line **119** by inverting the signal on line **118** in an inverter **188**. Another pair of AND gates **189** and **191** receive, respectively, the pairs of signals on lines **177** and **182** and on lines **178** and **183**. An OR gate **192** produces a reference signal on line **63** in response to inputs from the AND gates **189** and **191**. A complementary reference signal is generated on line **64** by inverting the line **63** signal in an inverter **193**.

Addition circuit **195** adds the signals on lines **178** and **182** producing a reference signal on line **125**. Also receiving this signal is a multiplier **196** that also receives the input control signal on line **107**. The output of multiplier **196** is combined with the control signal on line **108** in a divider **197** providing a modified reference signal on line **123**. Similarly, addition circuit **198** adds the signals on lines **178** and **183** producing a reference signal on line **126**. This signal is combined with the control signal on line **107** in the multiplier **199** the output of which is combined further with the control signal on line **109** in a divider **201** producing a modified reference signal on line **122**.

FIG. **9** illustrates in block circuit form the scanning pattern modulator **121** shown in FIG. **6**. Addition circuit **203** adds the square wave signals on input lines **114** and **116** producing a three-level raster control signal on line **204**. Similarly, addition circuit **205** adds the square wave input signals on lines **114** and **117** producing a three-level reference output signal on line **206**. The signal on line **204** is combined with the control signal on line **107** in a multiplier **207** producing an amplitude modulated raster control signal on line **151** while the signal on line **206** is combined with the control signal on line **107** in multiplier **208** producing an amplitude modulated raster control signal on output line **152**. Each of output lines **151** and **152** are connected to ground by contacts **209** controlled, respectively, by electronic switches **211** and **212** responsive to reference signals on lines **118** and **119**. Combining the signals on lines **147** and **152** to produce a modulated error signal on line **153** is a multiplier **213**. An identical multiplier **214** combines the signals on lines **146** and **151** producing a modulated error signal on line **154**. Similarly, the signals on lines **145** and **151** are combined by multiplier **215** and the signals on lines **148** and **152** are combined in multiplier **216** producing modulated error signals on lines **155** and **156**.

Typical waveforms generated on certain lines of the system are illustrated in FIG. **10**. Each waveform is identified by the reference numeral applied to the signal line on which it appears and the various waveforms are related to each other in a time sense. As shown, the time base circuit **111** (FIG. **7**) produces similar square wave signals on lines **114** and **117**. However, because of the slightly different frequency reduction factors introduced by the dividers **167** and **168**, the frequency of the square wave signal on line **114** is slightly higher than that of the signal produced on line **117**. Also produced in the time base circuit **111** on line **113** and shown in FIG. **10** is the complement of the waveform on line **114**, i.e., the voltage on line **113** is positive when the voltage on line **114** has a zero value and is zero when the voltage on line **114** is positive. Similarly produced by time base circuit **111** on line **116** and shown in FIG. **10** is a waveform complementary to that produced on line **117**.

In waveform generator **106** (FIG. **8**) the AND gate **185** produces a positive output only during periods wherein positive voltages are simultaneously present on signal lines **113** and **116**. Likewise, AND gate **186** produces a positive output only during periods wherein positive voltages are simultaneously present on lines **114** and **117**. OR gate **187** produces a positive output on signal line **118** in response to reception of positive signal values from either of the AND gates **185** or **186** thereby providing the waveform illustrated in FIG. **10**. This signal is inverted by the inverter **188** producing the complement thereof on signal line **119** as also illustrated in FIG. **10**.

Addition in the scanning pattern modulator **121** (FIG. **9**) of the signals on lines **114** and **116** produces on line **104** the three-level waveform shown in FIG. **10**. This waveform has a zero value during periods of positive voltages on either lines **114** and **116**, a positive value during periods of positive voltage on both lines **114** and **116** and a negative value during zero voltage periods on both lines **114** and **116**. Similarly added by the addition circuit **205** are the signals on lines **114** and **117** producing on signal line **206** the three level waveform also shown in FIG. **10**. After amplitude modulation by control signal **107** in the multipliers **207** and **208**, respectively, the three level waveforms generated on lines **204** and **206** are fed on lines **151** and **152**, respectively, into the sum and difference circuit **157** (FIG. **6**). There, as described in greater detail below, the signals are again amplitude modulated by error signals received from the scanning pattern modulator **121** on lines **153–156**. Resultant amplitude corrected signals of one sense appear on lines **158** and **159** and corrected signals of the opposite sense appear on output lines **160** and **161**. After integration in integrator network **162** (FIG. **6**) and a voltage to current amplification by amplifiers **163**, these signals result in raster control signals on lines **58** and **59** that are applied to the *x* and *y* deflection coils of cathode ray tube **26** (FIG. **1**) and raster control signals on lines **61** and **62** that are applied to the deflection coils of cathode ray tube **27**. The raster control signals on lines **68, 59** and **61** and **62** have the triangular forms illustrated in FIG. **10** and generate, as described below, rasters with orthogonally related *x* and *y* scanning paths as shown in FIG. **11**. Orientation of the cathode ray tube deflection coils is such that the *x* and *y* scanning directions indicated in FIG. **11** correspond, respectively, to the *x* and *y* directions of movement defined by the *x*-rails **74** and *y*-rails **69** shown in FIG. **2**.

Referring again to FIG. **10** it will be noted that between times t_0 and t_1 there exists a decreasing current on raster x-control lines **58** and **61** and a constant current on *y*-control lines **59** and **62**. Therefore, the scanning beam spots move between points t_0 and t_1 (FIG. **11**) in a direction with negative *x* and zero *y* components. Between times t_1 and t_2 an increasing current appears on *y*-control lines **59** and **62** and a constant current appears on *x*-control lines **58** and **61**. Thus, the spots move between points t_1 and t_2 (FIG. **11**) in a direction with positive *y* and zero *x* components. Betwen times t_2 and t_3, an increasing current exists on *x*-control lines **58** and **61** and a constant current on *y*-control lines **59** and **62**. Consequently, as indicated by FIG. **11**, the scanning spots move between points t_2 and t_3 in a direction with positive *x* and zero *y* components. Between times t_3 and t_4 there is a decreasing current on *y*-control lines **59** and **62** and again a constant current on *x*-control lines **58** and **61** thereby producing the path direction indicated between points t_3 and t_4 in FIG. **11**. This path segment has negative *y* and zero *x* components. The spots then complete another negative *x* path segment between points t_4 and t_5. However, as shown in FIG. **10** the negative current value appearing on *y*-control lines **59** and **62** is greater than the constant current present during time period t_0 and t_1. Consequently, the path segment t_4–t_5 is outside the path segment t_0–t_1 in the scanning area A. Similarly, the constant current applied to *x*-control lines **58** and **61** during time period t_5 to t_6 is less than that applied during time period t_0 to t_2. Therefore, the path segment defined by points t_5 and t_6 in FIG. **11** lies inside the path segment defined by points t_1 and t_2. This failure of the path segments to coincide directly is caused by the slightly different signal frequencies produced by the dividers **167** and **168** in the time base circuit **11** (FIG. **7**). It will be obvious that the scanning pattern illustrated in FIG. **11** will continue with *x*-direction segments of decreasing length and *y*-direction segments of increasing length until a relative phase reversion occurs between the raster control signals on *x*-lines **58–61** and those on *y*-lines **59** and **62**. At that time, the *x*-direction segments will begin to progressively increase in length and the *y*-direction segments will begin to decrease in length providing complete coverage of the scanned frame area A.

Thus, the scanning spots directed by cathode ray tubes 26 and 27 onto corresponding areas of the stereo photographs 22 and 23 (FIG. 1) travel along continuous paths comprising alternating orthogonally related path segments. The x-direction sets of path segments represented in FIG. 11 by the lines joining point t_o and t_1, t_2 and t_3, t_4 and t_5, t_6 and t_7, and t_8 and t_9 are parallel to the sense of x-parallax detected and corrected in the photographic transparencies 22 and 23 while the y-direction sets of path segments represented by lines between points t_1 and t_2, t_3 and t_4, t_5 and t_6, and t_7 and t_8 are parallel to y-parallax corrected therein. Furthermore, it will be noted by reference to FIG. 10, that either of the reference signals on lines 118 or 119 indicates in which of those path segment sets the scanning spot is moving. For example, the signal on line 118 is positive during $\pm x$-direction spot movement and zero during $-$ y-direction spot movement. Conversely, the signal on line 119 is positive during $\pm y$-direction spot movement and zero during $\pm x$-direction spot movement. The advantages derived from the illustrated scanning pattern and associated reference signals will be described in greater detail below.

FIG. 12 illustrates circuit details of the adaptive control circuit 105 shown in FIG. 6. After being smoothed in an integrating amplifier 218 and inverted in an inverter 219 the y cross-correlation component on input line 56 is fed into a limit circuit 221. This circuit produces a y-gain control signal on line 108. Included in the limit circuit 221 is an operational amplifier 222 and parallel resistor 223. A pair of potentiometers 224 and 225 are connected between the output of the amplifier 222 and a negative voltage source 226. Connected between the input of the amplifier 222 and the adjustable terminals of, respectively, the potentiometers 224 and 225 are clamping diodes 227 and 228 that provide maximum and minimum outputs for the limit circuit 221.

A limit circuit 229 identical to limit circuit 221 receives the x cross-correlation component on line 55 after smoothing in the integrating amplifier 230 and inversion in an inverter 231. The circuit 229 produces an x-gain control signal on line 109. Also receiving the smoothed y and x cross-correlation components are, respectively, threshold circuits 233 and 234 that provide track and hold control signals on lines 141 and 142. Summing resistors 235 combine the parallax error signal on line 133 after inversion in an inverter 232, the orthogonal correlation signal on line 58, and the x cross-correlation output of inverter 231. These combined signals are passed into a limit circuit 236 also identical to the limits circuits 221 and 229. Circuit 236 provides a raster control signal on line 107. A summing amplifier 237 sums the signals applied to resistors 238 including the x-parallax signal output on line 133, the orthogonal correlation signal on line 58, and the x cross-correlation output of inverter 231. Also received by summing amplifier 237 from a charging circuit 239 is an output proportional to the rate of change of the x cross-correlation signal output of inverter 231. The charging circuit 239 includes a capacitor 241 and a diode 242 connected in series with the resistor 243. Connected between ground and the junction between diode 242 and resistor 243 is the parallel combination of a compacitor 244 and resistor 245. Another diode 246 is connected between ground and the junction between the capacitor 241 and diode 242. The maximum value of the velocity control signal output on line 143 is established by the clamping diode 248 and potentiometer 249.

FIG. 13 illustrates in block circuit form the distortion analyzer 127 shown in FIG. 6. Receiving the reference signals on lines 125 and 126 are, respectively, integrator circuits 251 and 252. The output of integrator 251 on line 253 is fed into each of a pair of multipliers 254 and 255. Similarly, the output of integrator 252 on line 256 is fed into each of a pair of multipliers 257 and 258. The multipliers 254 and 257 also receive the input signal on line 131 and produce error signals on, respectively, lines 136 and 137. The input signal on line 132 is applied to each of the multipliers 255 and 258 which produce output error signals on, respectively, lines 138 and 139.

FIG. 14 illustrates in block circuit form the parallax analyzer 128 shown in FIG. 6. A multiplier 261 combines the reference signal on line 125 with the orthogonal correlation signal on line 58 producing an output signal on line 131. Similarly, multiplier 262 combines the reference signal on line 126 with the orthogonal correlation signal on line 58 producing an output signal on line 132.

FIG. 15 shows in block circuit form the adaptive parallax analyzer 124 shown in FIG. 6. A multiplier 263 combines the reference signal on line 122 with the orthogonal correlation signal on line 58 producing an x-parallax error signal on line 133. Similarly, multiplier 264 combines the reference signal on line 123 with the orthogonal correlation signal on line 58 producing a y-parallax error signal on line 134.

FIG. 16 illustrates circuit details of the track and hold integrator circuit 135 shown in FIG. 6. The error signal on input line 136 is received by the integrator circuit 271 that produces a controlled output error signal on line 145. Included in the integrator circuit 271 is an operational amplifier 272 and parallel capacitor 273. Connecting the input on signal line 136 to the input of amplifier 272 are the series connected resistor 274 and field effect transistor switch 275. A resistor 276 is connected between the junction of resistor 274 and transistor switch 275 and the output of the amplifier 272. Applied to control electrode 277 of transistor switch 275 is the control signal on line 141. An integrator circuit 281 identical to circuit 271 receives the error signal on line 137 and provides a controlled output error signal on line 146. Also applied to transistor switch 282 in the integrator circuit 281 is the control signal on line 141. Another identical integrator circuit 283 receives the error signal on input line 138 and provides on line 147 an output error signal. This output is controlled by the control signal on line 142 which is applied to transistor switch 284 in the integrator circuit 283. Similarly, integrator circuit 286 transmits the error signal on line 139 to output line 148 under the control of the control signal on line 142 applied to transistor switch 285. Finally, the again identical integrator circuits 288 and 289, respectively, transmit the x-parallax error signal on line 133 to output line 144 and the y-parallax signal on line 134 to output line 135' under the control of the signal on line 142 applied to control electrodes of transistor switches 287 and 290.

To further explain operation of the invention reference is again made to FIG. 5. The cross-correlation signal selected by channel selector **95** is fed into the gates **98** and **99** which also receive, respectively, gating signals on lines **64** and **63.** These signals are produced in the waveform generator **106** shown in FIG. **8.** As described above, the flip flop **175** is triggered by trailing edges of the pulses on line **112** received after a slight delay in the delay circuit **176.** Thus, the complementary square wave signals generated on lines **177** and **178** have a frequency one half that of the square wave signal on line **112** and with a slightly lagging phase relationship determined by the delay circuit **176.** However, since the frequency of the signal on line **112** is exactly twice that of the complementary signals **113** and **114** it will be apparent that the signals produced on lines **177** and **178** have waveforms identical to those illustrated for lines **113** and **114** in FIG. **10.** Similarly, the complementary signals produced by the flip flop **179** on lines **182** and **183** have waveforms identical to those illustrated in FIG. **10** for lines **116** and **117** except for the slight time delay established by the delay circuit **181.**

The signals on lines **177, 178, 182** and **183** are operated upon by the AND gates **189** and **191,** the OR gate **192** and the inverter circuit **193** in exactly the manner, described above, that signals on lines **113, 114, 116** and **117** are operated upon by AND gates **185** and **186,** OR gate **187** and the inverter circuit **188.** Consequently, the reference signal produced on lines **63** and **64** have waveforms identical to the waveforms illustrated for lines **118** and **119** in FIG. **10,** again except for the time lag established by the delay circuits **176** and **181.** These delays merely compensate for the inherent time delays introduced by the correlator and bandpass filter circuits **44, 45** and **46** (FIG. **1**) so as to insure time synchronization between the various reference signals and the orthogonal and cross-correlation signals produced by those circuits. Thus, for purposes of further circuit analysis, the waveforms illustrated for lines **113** and **114** in FIG. **10** can be considered identical, respectively, to those appearing on lines **177** and **178,** those illustrated for lines **116** and **117** identical, respectively, to those appearing on lines **182** and **183,** and those illustrated for lines **118** and **119** identical, respectively, to those appearing on lines **63** and **64.** These relationships are indicated by the appropriate signal line reference numerals applied to the right hand terminations of the waveforms illustrated in FIG. **10.**

Referring back now to FIG. **5,** the cross-correlation signal on line **97** is passed to filter **101** when gate **98** is gated by a positive voltage on line **64** and to filter circuit **102** when gate **99** is gated by a positive voltage on line **63.** As shown by the waveforms in FIG. **10,** the signal on line **63** is positive only during periods of voltage value transition on signal lines **58** and **61** which periods correspond to scanning spot movement in either the plus or minus *x*-direction. Similarly, the signal on line **64** is positive only during periods of voltage value transition on lines **59** and **62** which correspond to periods of scanning spot movement in either the plus or minus *y*-direction. Therefore, the signal component derived by the separator **54** on line **55** represents correlation quality during periods of scan in the *x*-coordinate direction and the component derived on line **56** represents correlation quality during periods of scan in the *y*-coordinate direction.

The *x* and *y* cross-correlation components on lines **55** and **56** along with the orthogonal correlation signal on line **58** are fed into the adaptive control circuit **105** shown in FIG. **12.** Receiving the *y*-component after smoothing and inversion in circuits **218** and **219,** respectively, is the limit circuit **221** that produces on line **108** a *y*-gain control signal of proportional value within the maximum and minimum limits determined by adjustment of the potentiometers **224** and **225.** In the same manner, the *x*-component after smoothing and inversion in circuits **230** and **231,** respectively is applied to the limit circuit **229** that produces on line **109** an *x*-gain control signal of proportional value within predetermined maximum and minimum limits. The *x* and *y* gain signals on lines **107** and **108,** respectively, are used to control *x* and *y*-loop gains as described below.

The *y* and *x* cross-correlation components are also applied, respectively, to the threshold detector circuits **233** and **234** after being smoothed by the amplifiers **218** and **230.** When the value of the *y* cross-correlation component is above a predetermined threshold value, a control signal appears on output line **141.** Similarly, when the amplitude of the *x* cross-correlation component is above a predetermined threshold value, a control signal is present on output signal line **142.** As described below, these signals modify the *x* and *y* correction outputs in the track and hold integrator network **135.**

Also receiving the *x* cross-correlation component in addition to the orthogonal correlation signal on line **58** and the *x*-parallax error signal on line **133** after inversion by inverter **232** is the summation amplifier and limit circuit **236.** The raster size control signal output of the limit circuit **236** on line **107** is proportional to the degree of *x*-parallax indicated by the signal on line **133** and inversely proportional to both correlation quality in the *x*-direction as indicated by the *x* cross-correlation component on line **55** and the magnitude of raw parallax indicated by the orthogonal correlation signal on line **58.** As described below this signal controls raster size in the scanning pattern modulator **121** (FIG. **6**) and *x* and *y* loop gains in the waveform generator **106.**

The summing amplifier and limit circuit **237** receives the *x* cross-correlation component, the orthogonal correlation signal on line **58** and the *x*-parallax error signal on line **133,** all applied to summing resistors **238.** Within a predetermined maximum range determined by clamping diode **248** and potentiometer **240,** the output of summing amplifier **237** on line **143** is a traversing velocity control signal with a value proportional to the quality of *x*-direction correlation as indicated by the *x* cross-correlation component and inversely proportional to both the orthogonal correlation signal on line **58** and the *x*-parallax error signal on line **133.** As illustrated in FIG. **6,** the velocity control signal on line **143** is applied through a servo amplifier to the *y*-servo motor **77** shown also in FIG. **2.** Thus, the *y*-carriage **67** is driven in the *y*-coordinate direction established by the *y*-rails **69** at a velocity inversely proportional to the degree of raw distortion indicated by the orthogonal correlation signal and to the degree of *x*-parallax indicated by the *x*-parallax error signal and proportional to correlation quality in the *x*-direction of scan as indicated by the *x* cross-correlation component.

Also applied to summing amplifier **237** via resistor **243** is the output of charging circuit **239** which functions as a differentiator. Thus, the output to resistor

243 reflects the rate of change of the x cross-correlation input signal. Since this signal also controls the amplifier output on line 143, it will be obvious that the velocity of y-servo motor 77 is also influenced by the rate at which x-correlation quality changes. Consequently, during periods of rapid correlation quality change the velocity of the y-direction traverse can be quickly altered in magnitude or even caused to reverse direction.

Referring now to the parallax analyzer 128 shown in FIG. 14, the orthogonal correlation signal on line 58 is operated upon in the conventional four-quadrant multiplier circuits 261 and 262 producing on lines 131 and 132, respectively, error signals that represent y and x-parallax. The output of multiplier 261 is determined by the polarity of the y-reference signal on line 125 and the output of the multiplier 262 is determined by the polarity of the x-reference signal on line 126. As shown by FIG. 10, the signal on reference line 125 is positive during periods of scan in the positive y-direction, zero during periods of x-direction scan of either sense, and negative during periods of negative y-direction scan. The reference signal on line 125 eliminates those portions of the orthogonal correlation signal representing relative distortion in the x-direction of scan and compensates for the polarity reversals caused by opposite y-scan directions. Thus, the y-parallax error signal on line 131 indicates both degree and sense of y-parallax existing between the compared images. Similarly, the x-reference signal on line 126 has a negative value during periods of negative x-direction scan, a zero value for either sense of y-direction scan, and a positive value during periods of positive x-direction scan. The reference on line 126 eliminates those portions of the orthogonal correlation signal representing relative distortion in the y-scan direction and compensates for the opposite directions of x-direction scan to produce on line 132 a signal indicating both the degree and sense of x-parallax existing between the compared images.

The x and y-parallax signals on lines 132 and 131 are applied to the distortion analyzer 127 shown in FIG. 13. Also received by the distortion analyzer 127 on lines 125 and 126 are y and x reference signals that are integrated, respectively, by the integrator circuit 251 and 252. The resultant waveforms on lines 253 and 256 are, as indicated in FIG. 10, identical in form to the deflection signals produced on, respectively, lines 59 and 62 and lines 58 and 61. Combined in the four-quadrant multiplier 258 are the x-parallax error signal on line 132 and the reference signal on line 256 which is negative during periods of x-direction spot movement in the left half of the scanning area A (FIG. 11) and positive during x-direction spot movement in the right half of the scanning area. Therefore, the output signal of multiplier 258 on line 139 represents magnitude and sense of x-scale error existing between the compared images. Applied to the four-quadrant multiplier 255 are the x-parallax error signal on line 132 and the reference signal on line 253 which, as shown in FIG. 10, is negative during periods of spot movement in the negative x-direction and positive during spot movement in the positive x-direction. Accordingly, the output of multiplier 255 on line 138 respresents both magnitude and sense of x-skew error existing between the compared images. The four-quadrant multiplier 254 receives the y-parallax error signal on line 131 and the reference signal on line 253 which is negative during periods of y-direction spot movement in the lower half of the scanning area A and positive during periods of y-direction spot movement in the upper half of the scanning area A. Thus, the output signal of multiplier 254 on line 137 represents both magnitude and sense of y-scale error existing between the compared images. Finally, the four-quadrant multiplier 257 receives the y-parallax error on line 131 and the reference signal on line 256 which is negative during periods of scanning spot movement in the positive y-direction and positive during periods of scanning spot movement in the negative y-direction. Consequently, the output of the multiplier 257 on line 136 represents magnitude and sense of y-skew error existing between the compared images. A more thorough discussion of the first-order distortions x-scale, x-skew, y-sale and y-skew and methods for their detection appears in the above noted U.S. Pat. No. 3,432,674. Additional control of the error signals on lines 136–139 occurs in integrater network 135 (FIG. 6), as described in greater detail below.

Reference is now made to the adaptive parallax analyzer 124 shown in FIG. 15. The orthogonal correlation signal on line 58 is operated upon in four-quadrant multipliers 263 and 264 by the reference signals on lines 122 and 123, respectively. This produces x and y-parallax error signals on output lines 133 and 134 in exactly the manner described above in connection with parallax analyzer 128 shown in FIG. 14. However, as described above, the reference signals on lines 122 and 123 are amplitude modulated in waveform generator 106 (FIG. 8) by the raster control signal on input line 107 and the y and x-loop gain control signals on, respectively, lines 108 and 109. The multiplier circuits 196 and 199 increase the amplitudes of the reference signals on lines 125 and 126, respectively, in response to increasing values of the raster control signal on line 107. Conversely, the divider circuits 197 and 201 decrease the amplitudes of the associated reference signals in response to increasing values of the loop gain control signals on lines 108 and 109, respectively. Thus, the amplitude of the error signal output of adaptive parallax analyzer 124 on line 133 is proportional to both the level of x-parallax existing between the compared images and the value of the raster control signal on line 107, and inversely proportional to the value of the x-loop gain control signal on line 109. The output on line 134 is an error signal with an amplitude proportional to both y-parallax existing between the compared images and the value of the raster control signal on line 107, and inversely proportional to the value of the y-loop gain control signal on line 108.

Referring now to the track and hold integrater network 135 shown in FIG. 16, integrator circuits 271 and 281 normally pass onto output lines 145 and 146, respectively, the y-skew and y-scale error signals received from the distortion analyzer 127 on signal lines 136 and 137. However, if correlation quality in the y-direction of scan as indicated by the y cross-correlation component falls below a predetermined level established by the threshold of detector circuit 233 (FIG. 12), control voltage is eliminated from hold-control line 141. The elimination of this control voltage opens transistor switches 275 and 282 of integrator circuits 271 and 281, respectively. This in turn prevents further changes in the line 145 and line 146 output voltages which are maintained at existing levels by the charged capacitors 273. Similarly, integrator circuits 283 and 286 normally pass onto output lines **147** and **148**, respectively, the *x*-skew and *x*-scale error signals received on lines **138** and **139** from distortion analyzer **127**. However, in response to a decrease in *x*-direction correlation quality, as indicated by the *x* cross-correlation component, to below a minimum level established by the threshold of detector circuit **234** (FIG. **12**), control voltage is eliminated from the hold-control line **142**. This in turn opens the field effect transistor switches **284** and **285** in integrator circuits **283** and **286** preventing further changes in line **147** and line **148** output voltages which are maintained at previous values by the charged capacitors **273**.

Also received by track and hold integrator network **135** are the x and y parallax error signals derived by adaptive parallax analyzer **124** (FIG. **15**) on lines **133** and **134**, respectively. These signals are normally passed by integrator circuits **288** and **289** (FIG. **16**) on lines **144** and **135'**, respectively, to the *z*-servo motor **83** and output line **59** of the integrator network **162** (FIG. **6**). Again, however, a decrease in *x*-direction correlation quality to below a predetermined level results in elimination of control voltage from hold-control line **142**. This opens the transistor switches **287** and **290** preventing further change on line **135'** and line **144** output voltages which are maintained at existing values by charged capacitors **273**.

As described above, the *z*-motor **83** produces vertical movement of *z*-carriage **81** (FIG. **2**) and corresponding rectilinear relative movement between the transparencies **22** and **23** so as to correct *x*-parallax existing therebetween. The *x*-parallax is represented partially by the amplitude of the error signal input to integrator **288** on line **133**. However, as noted above, the signal on line **133** has an amplitude proportional also to the raster control signal on line **107** (FIG. **12**) and inversely proportional to the value of the *x*-gain control signal on line **109** in turn established in control circuit **105** (FIG. **12**) by *x*-direction correlation quality as indicated by the *x* cross-correlation component. Thus, the gain of the *x*-parallax transformation system is dependent upon both the size of the scanning raster utilized and upon correlation quality in the *x*-direction of scan as indicated by the *x* cross-correlation component. Furthermore, the absence of a given minimum level of correlation quality in the *x*-direction results in the above holding action that prevents changes in a then applied magnitude and sense of *x*-parallax correction.

The error signals produced by the track and hold integrator network **135** (FIG. **16**) on lines **145–148** are fed into the scanning pattern modulator **121** shown in FIG. **9**. There, the *x*-reference signal on line **152** is amplitude modulated by the *x*-skew error signal on line **147** and the *x*-scale error signal on line **148** in, respectively, the four-quadrant multiplier circuits **213** and **216**. This results in output signals on lines **153** and **156** having three level waveforms time related to the reference signal on line **152** but with amplitudes respectively proportional to detected *x*-skew error and *x*-scale error. Similarly, the *y*-reference signal on line **151** is amplitude modulated by the *y*-scale error signal on line **146** and the *y*-skew error signal on line **147** in, respectively, the four-quadrant multipliers **214** and **215**. The resultant output signals on lines **154** and **155** have three level waveforms time related to the reference signal on line **151** but with amplitudes respectively proportional to detected *y*-scale error and *y*-skew error.

FIG. **17** shows in block diagram form the sum and difference circuit **157** shown in FIG. **6**. Applied to a summing amplifier **301** are the *x*-raster control signal on line **152**, the *x*-skew error signal on line **153**, and the *x*-scale error signal on line **156**. The same three signals are applied also to a summing amplifier **302** after polarity reversal, however, of the reference signal on line **152** in an inverter circuit **303**. The resultant output signals on lines **159** and **161** have waveforms of the three level type illustrated for line **206** in FIG. **10** but with amplitude corrections of opposite sense introduced by the error signals on lines **153** and **156**. Another summing amplifier **304** receives the *y*-raster control signal on line **151**, the *y*-scale error signal on line **154** and the *y*-skew error signal on line **155**. Similarly, applied to a summing amplifier **305** are these same signals after polarity reversal of the *y*-raster control signal on line **151** in an inverter circuit **306**. Again, the output signals on lines **158** and **160** have waveforms of the three level type illustrated for line **204** in FIG. **10** but with amplitude corrections of a degree determined by the error signals on lines **154** and **155** and of opposite sense because of the inverter **306**.

The error signal modulated voltages on lines **157** and **161** are integrated in the integrator network **162** (FIG. **6**) producing on lines **58** and **61** the triangular type waveforms shown in FIG. **10**. These currents are applied, respectively, to the *x*-deflection coils of cathode ray tubes **26** and **27**. Integration of the error signal modulated voltages on lines **158** and **160** produces on lines **59** and **62** the triangular waveforms also shown in FIG. **10**. The line **59** and line **62** signals are applied, respectively, to the y-deflection coils of cathode ray tubes **26** and **27**. The deflection signals on lines **58**, **59**, **61** and **62** distort the scanning rasters produced by tubes **26** and **27** in a manner tending to eliminate the *x*-scale, *x*-skew, *y*-scale and *y*-skew errors represented by the corresponding error signals. Because of the opposite senses of correction introduced in sum and difference circuit **157**, the distortion of the rasters also are of opposite sense. For example, an *x*-scale error signal on line **156** indicating a larger *x*-scale for the image on transparency **22** than for the image on transparency **23** would tend to enlarge the raster *x*-scale of tube **27** and reduce the raster *x*-scale of tube **26**. A further description of these raster corrections appears in the above noted U.S. Pat. No. 3,432,674.

Y-parallax is corrected by combining the *y*-parallax error signal on line **135'** with *y*-deflection voltage on line **59** as shown in FIG. **6**. The bias introduced by the line **135'** signal shifts the raster generated by cathode ray tube **26** so as to produce relative rectilinear movement between the areas scanned in the two images. This relative movement is in the direction defined by *y*-rails **69** (FIG. **2**) and of a sense tending to correct *y*-parallax indicated by the parallax error signal on line **135'**.

Thus, the present invention provides a dual image registration system that automatically controls scanning pattern size in dependence upon correlation quality in the *x*-direction of scan as indicated by the *x* cross-correlation component, raw levels of misregistration indicated by the orthogonal correlation signal, and levels of *x*-parallax indicated by the derived *x*-parallax signal. The raster size control signal is generated in the adaptiive control circuit **105** (FIG. **6**) and used to amplitude modulate the raster reference signals in the scanning pattern modulator **121**. Also automatically controlled is profiling speed in dependence upon both correlation quality and rate of change of correlation quality in the x-direction of scan, raw levels of misregistration, and levels of x-parallax. The profiling velocity control signal is generated in the adaptive control circuit **105** (FIG. **6**) and applied to the y-servo motor **77**. Further provision is made for automatically controlling electrical gain of the x-parallax and y-parallax correction loops. The x-loop gain is controlled by correlation quality in the x-direction of scan and by raster size while y-loop gain is controlled by correlation quality in the y-direction of scan and also by raster size. These control signals are generated in adaptive control circuit **105** (FIG. **6**) and used in waveform generator **106** to amplitude modulate x and y-reference signals applied to the adaptive parallax analyzer **124**. Finally, all x and y corrective transformations are automatically stopped in response to predetermined conditions indicated by the levels of the x and y cross-correlation components.

During normal operation correlation is initially established using image detail of low spatial frequency to secure a good pull-in capability, progressing to higher spatial frequencies to obtain higher accuracy. This selection is made by the channel selector **95** shown in FIG. **5**. The size of the scanning patterns are similarly reduced as correlation quality improves, and the profiling speed is increased. A sudden drop in correlation quality produces a rapid shift to correlation of lower spatial frequencies, to a larger scanning pattern and to a slower profiling rate. In extreme cases the y-servo will cause the machine to stop profiling or even to back up while correlation is restored.

A primary feature of the correlation system is that while the scanning patterns are completely amorphous in their ability to detect image displacements, the quality of correlation is monitored separately in the x and y-directions of scan producing distinct x and y-quality signals. Because of selective use of the separate correlation quality components loss of correlation in either axis separately does not produce failure, but merely results in a hold of the corresponding transformations at existing values until correlation in that axis is reestablished. Other correlation quality functions also are made more relevant by use of the appropriate cross-correlation component.

Another significant feature of the invention is the use of Lissajous type scanning patterns formed by a limited number of scanning lines per frame. Since the basic object of the system is to generate transformation error signals rather than to produce visible presentations, a small number of lines introduces no visual problems and facilitates the use of a desirable high frame rate. In addition, a larger scanning spot can be utilized for given sized rasters thereby providing more light for generation of video signals. According to the invention the oscillator **165** (FIG. **7**) is selected to provide raster signals on lines (**58, 61**) and (**59, 62**) with frequencies f_1 and f_2 and wherein f_1/f_2 expressed in its lowest terms is p/q where p and q are integers and $(p+q)$ is less than 100. In a specifically preferred embodiment p equals 16 and q equals 15 so that $(p+q)$ is equal to 31.

Obviously, many modifications and variations of the present invention are possible in light of the above teachings. It is to be understood, therefore, that the invention can be practiced otherwise than as specifically described.

What is claimed is:

1. A multiple image registration system comprising scanning means for directing scanning patterns onto corresponding areas of a pair of similar images; signal generating means for producing a first analog signal representing variable detail along the path scanned in one of said images, and a second analog signal representing variable detail along the path scanned in the other of said images; correlating means for deriving from said first and second analog signals an orthogonal correlation signal having an amplitude proportional to the degree of image detail misregistration along said scanned paths, and a cross-correlation signal having an amplitude proportional to the level of correlatable image detail along said scanned paths; waveform generating means providing for said scanning means raster signals that produce continuous scanning paths formed by alternating substantially orthogonally related crossing path segments; and actuating means comprising an x-parallax correction means responsive to said orthogonal correlation signal and adapted to produce a first direction of relative rectilinear movement between the areas scanned in said images, and wherein one set of said orthogonally related path segments are parallel to said first direction of relative rectilinear movement produced by said x-parallax correction means.

2. A multiple image registration system according to claim **1** wherein said waveform generating means further provides a scanning direction reference signal that indicates which of the orthogonally related sets of path segments is being scanned.

3. A multiple image registration system according to claim **2** wherein said correlating means separates from said cross-correlation signal an x-component derived during periods of scan along one of said path segment sets.

4. A multiple image registration system according to claim **3** including control circuit means adapted to vary the size of said scanned areas responsive to said x-component of said cross-correlation signal.

5. A multiple image registration system according to claim **3** including traversing means adapted to simultaneously produce a given magnitude of relative velocity between both of said images and the scanning patterns directed thereon; and said control circuit means is further adapted to vary said given magnitude of relative velocity in response to the value of said x-component of said cross-correlation signal.

6. A multiple image registration system according to claim **5** wherein said control circuit is further adapted to vary said given magnitude of relative velocity in response to the rate of change in the value of said x-component of said cross-correlation signal.

7. A multiple image registration system according to claim **3** wherein said correlating means further separates from said cross-section signal a y-component during periods of scan along the other of said path segment sets.

8. A multiple image registration system according to claim **7** wherein said actuating means further comprises y-parallax correction means responsive to said orthogonal correlation signal and adapted to produce between the areas scanned in said images a second direction of relative rectilinear movement orthogonally related to said first direction of movement produced by said x-parallax correction means.

9. A multiple image registration system according to claim 8 including holding circuit means adapted to render said x-parallax correction means non-responsive to said orthogonal correction signal in response to a predetermined condition indicated by the value of said x-component of said cross-correlation signal.

10. A multiple image registration system according to claim 9 wherein said holding circuit means is further adapted to render said y-parallax transformation means non-responsive to said orthogonal correlation signal in response to a given condition indicated by the value of said y-component of said cross-correlation signal.

11. A multiple image registration system according to claim 10 wherein said actuating means further comprises first order transformation means responsive to said orthogonal correlation signal and adapted to correct relative first order distortion between the scanned images.

12. A multiple image registration system according to claim 11 wherein said holding circuit means is further adapted to render said first order transformation means non-responsive to said orthogonal correlation signal in response to given conditions indicated by the values of said x and y-components of said cross-correlation signal.

13. A multiple image registration system according to claim 12 including traversing means adapted to simultaneously produce a given magnitude of relative velocity between both said images and the scanning patterns directed thereon; and said control circuit means is further adapted to vary said given magnitude of relative velocity in response to the value of said x-component of said cross-correlation signal.

14. A multiple image registration system according to claim 13 wherein said control circuit means is further adapted to vary the size of said scanning patterns in response to said x-component of said cross-correlation signal.

15. A multiple image registration system according to claim 3 including holding circuit adapted to render said x-parallax correction means non-responsive to said orthogonal signal in response to a predetermined condition indicated by the value of said x-component of said cross-correlation signal.

16. A multiple image registration system according to claim 15 including control circuit means adapted to vary the size of said scanning patterns in response to said x-component of said cross-correlation signal.

17. A multiple image registration system according to claim 16 wherein said x-parallax correction means comprises a closed loop system, and said control circuit means is further adapted to vary the gain of said closed loop system in response to said x-component of said cross-correlation signal.

18. A multiple image registration system according to claim 17 wherein said control circuit means is further adapted to vary the gain of said closed loop system in response to changes in the size of said scanning patterns.

19. A multiple image registration system according to claim 18 wherein said control circuit means is further adapted to vary the size of said scanning patterns in response to said orthogonal correlation signal.

20. A multiple image registration system according to claim 17 including traversing means adapted to simultaneously produce a given magnitude of relative velocity between both said images and the scanning patterns directed thereon; and said control circuit means is further adapted to vary said given magnitude of relative velocity in response to the value of said x-component of said cross-correlation signal.

21. A multiple image registration system according to claim 20 wherein said control circuit is further adapted to vary the size of said scanning patterns in response to said orthogonal correlation signal.

22. A multiple image registration system according to claim 21 wherein said correlating means further separates from said cross-correlation signal a y-component during periods of scan along the other of said path segment sets.

23. A multiple image registration system according to claim 22 wherein said actuating means further comprises a y-parallax transformation means responsive to said orthogonal correlation signal and adapted to produce between the areas scanned in said images a second direction of relative rectilinear movement orthogonally related to said first direction of movement produced by said x-parallel correction means.

24. A multiple image registration system according to claim 23 wherein said holding circuit means is further adapted to render said y-parallax transformation means non-responsive to said orthogonal correlation signal in response to a given condition indicated by the value of said y-component of said cross-correlation signal.

25. A multiple image registration system according to claim 24 wherein said y-parallax transformation means is a closed loop system and said control circuit means is further adapted to vary the gain of said closed loop y-parallax transformation means in response to said y-component of said cross-correlation signal.

26 A multiple image registration system according to claim 25 wherein said control circuit means is further adapted to vary the gain of said closed loop y-parallax transformation means in response to changes in the size of said scanning patterns.

27. A multiple image registration system comprising scanning means for directing scanning patterns onto corresponding areas of a pair of similar images; signal generating means for producing a first signal representing variable detail along the path scanned in one of said images; and a second analog signal representing variable detail along the path scanned in the other of said images; waveform generating means providing for said scanning means raster signals of frequencies f_1 and f_2 that produce a Lissajous scanning pattern with crossing sets of scanning paths and wherein f_1/f_2 expressed in its lowest terms is p/q where p and q are integers and $(p + q)$ is less than 100, said raster signals producing continuous scanning paths formed by alternating orthogonally related path segments, and said waveform generating means further providing a scanning direction reference signal that indicates which of said sets of orthogonally related paths is being scanned; and correlating means for deriving from said first and second analog signals an orthogonal correlation signal having an amplitude proportional to the degree of image detail misregistration along said scanned paths, said correlating means including means for deriving from said first and second analog signals a cross-correlation signal having an amplitude proportional to the level of correlatable detail along said scanned paths, and means for separating from said cross-correlation signal an x-component

derived during periods of scan along one of said path segment sets.

28. A multiple image registration system according to claim 27 including control circuit means depicted to vary the size of said scanning patterns in response to said x-component of said cross-correlation signal.

29. A multiple image registration system according to claim 27 including traversing means adapted to simultaneously produce a given magnitude of relative velocity between both of said images and the scanning patterns directed thereon; and control circuit means adapted to vary said given magnitude of relative velocity in response to the value of said x-component of said cross-correlation signal.

30. A multiple image registration system according to claim 27 including actuating means comprising an x-parallax correction means responsive to said orthogonal correlation signal and adapted to produce a first direction of relative rectilinear movement between the areas scanned in said images, and wherein one of said orthogonally related path segment sets is parallel to said first direction of relative rectilinear movement produced by said actuating means.

31. A multiple image registration system according to claim 30 including holding circuit means adapted to render said x-parallax correction means non-responsive to said orthogonal correlation signal in response to a predetermined condition indicated by the value of said x-component of said cross-correlation signal.

32. A multiple image registration system according to claim 31 wherein said correlating means further separates from said cross-correlation signal a y-component during periods of scan along the other of said path segment sets.

33. A multiple image registration system according to claim 32 wherein said actuating means further comprises a y-parallax transformation means responsive to said orthogonal correlation signal and adapted to produce between the areas scanned in said images a second direction of relative rectilinear movement orthogonally related to said first direction of movement produced by said x-parallax correction means.

34. A multiple image registration system according to claim 33 wherein said holding circuit means is further adapted to render said y-parallax transformation means non-responsive to said orthogonal correlation signal in response to a given condition indicated by the value of said y-component of said cross-correlation signal.

35. A multiple image registration system comprising scanning means for directing scanning patterns onto corresponding areas of a pair of similar images; signal generating means for producing a first analog signal representing variable detail along the path scanned in one of said images, and a second analog signal representing variable detail along the path scanned in the other of said images; traversing means for simultaneously producing a given magnitude of relative velocity between both said images and said scanning patterns directed thereon; correlating means for deriving from said first and second analog signals on orthogonal correlation signal having an amplitude proportional to the degree of image detail misregistration along said scanned paths, and a cross-correlation signal having an amplitude proportional to the level of correlatable image detail along said scanned paths; actuating means for producing relative rectilinear movements between the areas scanned in said similar images in response to said orthogonal correlation signal; and holding circuit means independent of said traversing means and operatively coupled to said actuator means and adapted to prevent said actuating means from responding to said orthogonal correlation signal in response to a predetermined condition indicated by said cross-correlation signal.

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