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Hobrough

[11] **3,777,055**

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[54] **HEXAGONAL PATCH PRINTING FOR ORTHOPHOTO PRINTERS**

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[52] **U.S. Cl.** .... **178/6.7,** 250/220 SP, 356/2
[51] **Int. Cl.** **G01c 11/12**
[58] **Field of Search** .... 178/6.7 R, 6.7 A, 178/6.5; 356/2; 250/220 SP; 350/136; 355/71, 74

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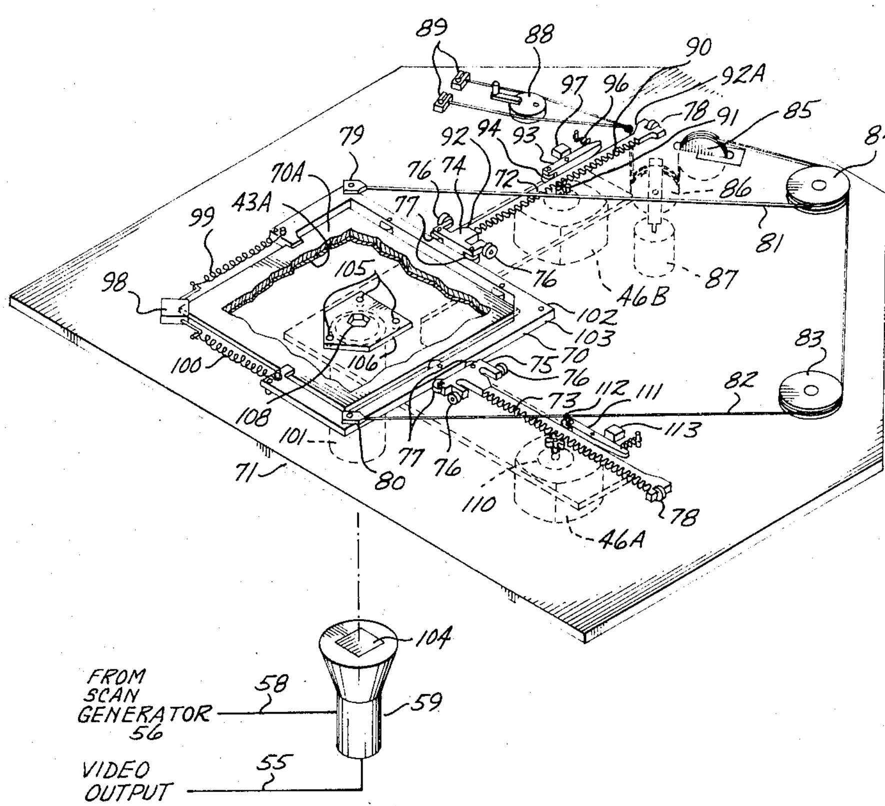
[57] **ABSTRACT**

A system is described for providing video signals from left and right stereo photographs which correspond to discrete, homologous areas thereof and which are compensated for parallax and other visual distortion errors. To print a portion of an orthophotograph corresponding to this video signal, a mask defining an hexagonal patch is interposed in the light path between a cathode ray tube for displaying the video signal, and a photographic negative. To construct the entire orthophoto, the negative is mounted on a photo printing device which moves the negative in discrete increments corresponding to selective scanning of corresponding areas in the left and right stero photographs.

7 Claims, 6 Drawing Figures



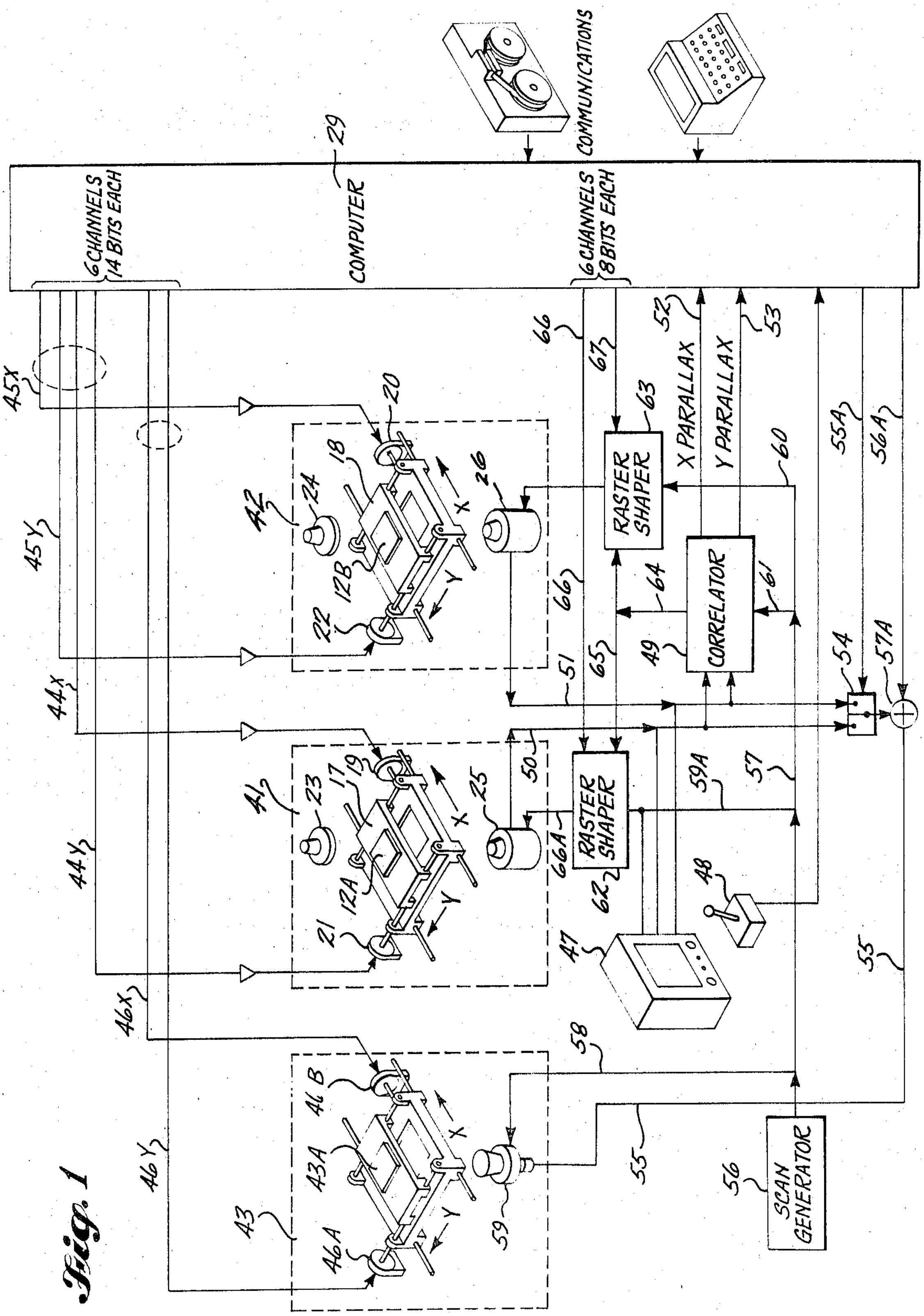

COMMUNICATIONS
COMPUTER
6 CHANNELS 14 BITS EACH
6 CHANNELS 8 BITS EACH
X PARALLAX
Y PARALLAX
RASTER SHAPER
CORRELATOR
RASTER SHAPER
SCAN GENERATOR

Fig. 1

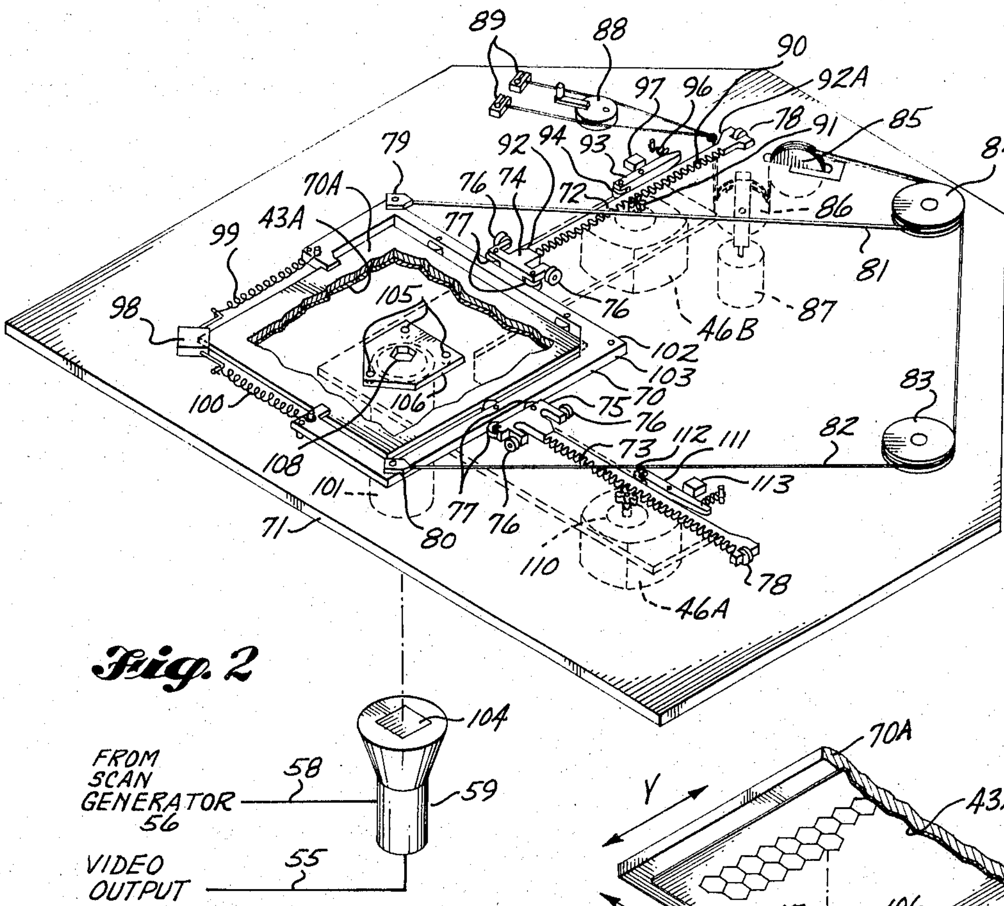


Fig. 2

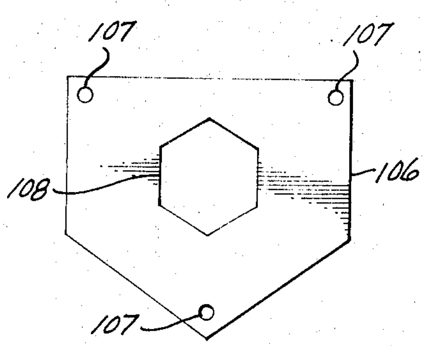


Fig. 3

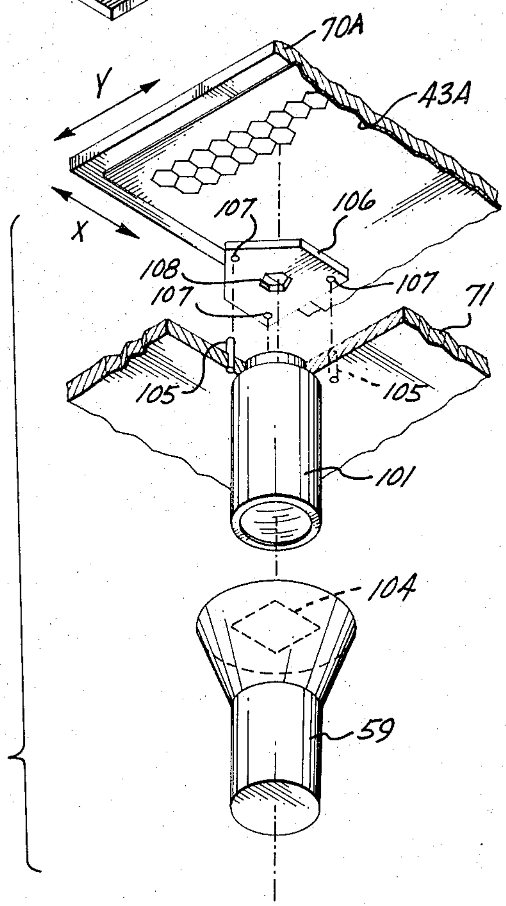


Fig. 4

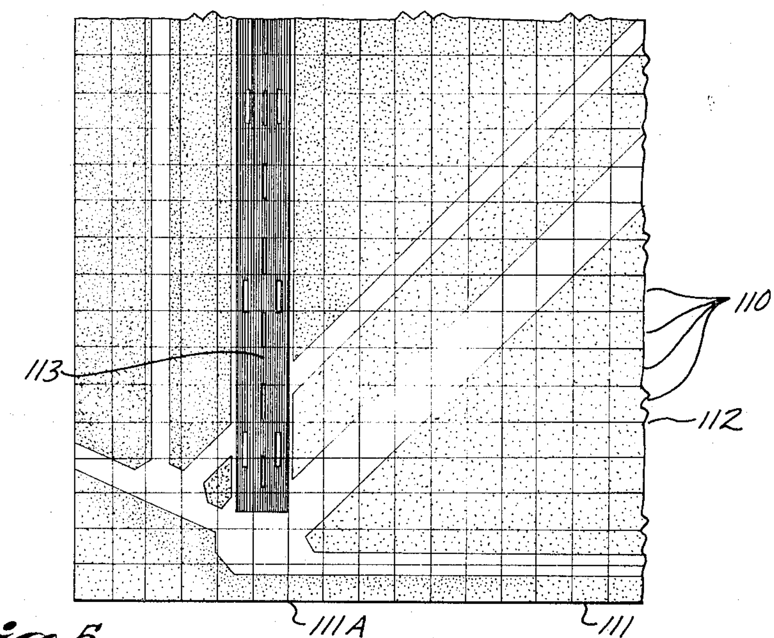


Fig. 5

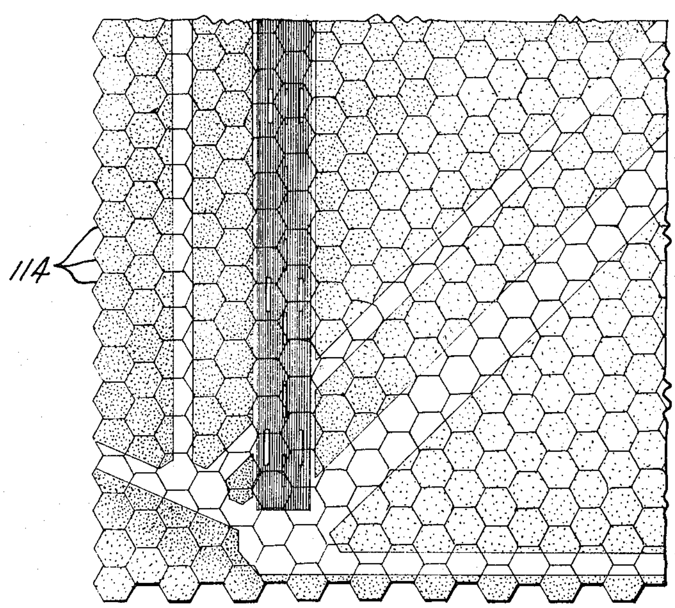


Fig. 6

HEXAGONAL PATCH PRINTING FOR ORTHOPHOTO PRINTERS

FIELD OF THE INVENTION

This invention generally relates to the field of automatic orthophoto printers, and more particularly, to an improvement in the printing of orthophotographs.

BACKGROUND OF THE INVENTION

An improved system which operates automatically to provide an orthophotograph for one or more pairs of stereo aerial photographs is described in my copending application entitled "Automatic Orthophoto Printer," U.S. Ser. No. 760,435, filed Sept. 18, 1968, now U.S. Pat No. 3,659,939 which is also assigned to the assignee of the present invention. This system greatly reduces the time necessary to produce an orthophotograph and includes first and second photo-scanning devices which are operated in synchronism to provide video signals for each of the two photographs making up a stereo pair. Homologous areas of the photographs are scanned, with the portion under consideration being termed the correlation zone. In order to reduce X and Y parallax of the video signals within the correlation zone, the system includes a correlation network which operates on the video signals to determine the amount of parallax error, and image transformation circuitry and raster shaping circuits controlled thereby for altering the scanning patterns of the two photo-scanning devices. Once the correlation zones of the two photographs have been brought into approximate registry by appropriate photo positioning devices, the system alters the scan pattern of one or both photo-scanning devices to reduce parallax and other errors to zero. One of the resultant video signals, which represents one image of the correlation zone, is supplied to a cathode ray tube for imprinting on the photographic negative. By investigating a number of correlation zones, an orthophotograph can be formed.

In order to increase the speed of orthphotograph production, each correlation zone should be as large as possible. The correlation zone size is determined by the image transformation capability of the system, and the printing method employed. With respect to the former, the complexity of the transformation that is required to eliminate parallax error generally increases with an increase in the area of the correlation zone. Accordingly, even with the **50th-order** transformation capability of the system described in the aforementioned copending patent application, there is a finite limit upon this area.

The path method of printing has proved itself adaptable to systems such as described in the aforementioned copending patent application. In the patch method, an image corresponding to the entire correlation zone is displayed on the face of a cathode ray tube and imprinted at one point in time after transformation has been completed.

However, the patch printing method is subject to limitations on the size and shape of the correlation zone due to (a) distortions in the reproduced image at the extremities of the CRT's scan, (b) limitations of the correlation process, and (c) limitations in matching patch boundaries mechanically and optically.

It is accordingly an object of this invention to provide an improved patch printing method for an automatic orthophoto printer.

Another object of this invention is to provide an improvement for an automatic orthophoto printing system which includes means for producing orthophotographs by the patch printing method in which the aforementioned limitations are minimized.

SUMMARY OF THE INVENTION

These objects and others are achieved by providing means defining a hexagonal mask in a light path between the face of a cathode ray tube on which the transformed image is displayed and the emulsion surface of a negative comprising the desired orthophoto.

DESCRIPTION OF THE DRAWINGS

The above as well as additional advantages and objects will be more clearly understood with reference to the following description, taken in conjunction with the accompanying drawings, in which:

FIG. **1** is a schematic diagram showing an automatic orthophoto printing system;

FIG. **2** is a pictorial view showing the output cathode ray tube and orthophoto printing mechanism of FIG. **1**;

FIG. **3** is a plan view of the hexagonal-mask-defining means shown in FIG. **2**;

FIG. **4** is another, exploded view of the apparatus illustrated in FIG. **2**;

FIG. **5** is a reproduction of an orthophotograph which was produced using the patch printing method of the prior art; and

FIG. **6** is a representation of the same orthophotograph but produced using the hexagonal patch printing method of this invention.

DESCRIPTION OF A PREFERRED EMBODIMENT

FIG. **1** is a system diagram of the elements of a preferred embodiment of the invention shown as an automated analytical plotter. Diapositives **12A** and **12B** corresponding to the stereo aerial photographs are mounted on the carriages **17** and **18** of the scanner and plate transport assemblies **41** and **42.** The plates are adapted for movement in the X and Y directions by the X drive motors **19** and **20** and the Y drive motors **21** and **22.** Light sources **23** and **24** illuminate the diapositives and provide light for the scanners **25** and **26** (which can be conventional TV pickup units). A scanning printer **43** contains a cathode ray tube **59** and an optical system for printing on sensitive film **43A**. A computer **29** which can be any of a number available on the market solves the basic resection-intersection equations and delivers stage coordinate commands to the scanners **41** and **42** and to printer **43,** on lines **44X, 44Y, 45X, 45Y,** and **46X, 46Y,** respectively. The electronic viewer **47** enables an operator to observe the images being scanned. A steering control **48** delivers instructions to the computer during manual operations. The electronic correlator **49** generates X and Y parallax error signals in response to timing differences between corresponding elements of the left and right video signals on output lines **50** and **51** from scanners **25** and **26.**

The operation of the system illustrated in FIG. **1** is as follows. First, a sequential program establishes a pair of model coordinates for examination. Stage coordinate signals are delivered to the printer **43** along lines **46X,** and **46Y,** causing the sensitive film **43A** in the printer **43** to assume a position corresponding to the selected model coordinate. Second, stage coordinates for the left and right scanners are computed on the basis of an initial or arbitrary terrain height (Z) evaluation for the center of the scanned area and such coordinate signals are delivered on lines **44X, 44Y** and **45X, 45Y** to actuate the transports **41, 42,** respectively. The correlator operates on the left and right video signals, on lines **50** and **51** respectively, to determine the X and Y parallax errors of the scanned area. The X parallax error signal from the correlator is delivered to the computer along line **52.** On the analysis of this signal, the computer center can order a modification of the initial Z value in a direction that will reduce the center X parallax error to zero. The computer re-evaluates the stage coordinates of the scanners on the basis of the new Z value and delivers modified stage coordinates to the left and right scanners on lines **44X, 44Y** and **45X, 45Y** respectively. The motion of the transport is electronically compensated for by the simultaneous cancellation from the "memory" of the correlator of this center-point Z value. In this manner, the "range" of the correlator's memory is optimized about the center point of the scanned area. The process of analysis of the X parallax error on line **52** and the determination of a new Z coordinate continues iteratively until the center-point X error (a zero-order signal) has been reduced to an acceptable level that has made optimum use of the correlator's memory. An average Y parallax signal on line **53** is also delivered to the computer and is used during setup and orientation of the model to generate new stage coordinates for the scanners in the Y direction. After orientation the Y parallax signal should be zero but during compilation of the model the computer responds to Y parallax error signals to compensate for the effects of film shrinkage, optical distortions, etc.

The printer **43** shown in FIG. **1** produces an orthophotograph on sensitive film **43A** therein. The cathode ray tube in the printer **43** is scanned synchronously with the scanners **25** and **26** and one of the video signals from the scanners is used to modulate the light intensity of the scanning spot in the printer. In FIG. **1,** the video signal from a left or right scanner is delivered along line **50** or **51** through the scanner selector switch **54** and along line **55** to printer **43.** Normally, the left video signal is selected for printing areas towards the left of the model and the right video signal is selected for printing areas towards the right of the model. For this purpose a left-right signal from computer **29** is delivered to selector switch **54** along line **55A.** The computer also delivers an inhibit signal on line **56A** that is combined in summing circuit **57A** with the video signal from switch **54.** The inhibit signal blanks the light output from cathode ray tube **59** to zero except during the desired printing period.

The scan generator **56** produces deflection wave forms required for scanning the diapositives and sensitive film. T0e scanning pattern or "raster" is normally square, but as discussed below the "raster" signals for scanners **25** and **26** are shaped as required for registration. In FIG. **1** the deflection wave forms from scan generator **56** are delivered along line **58** to the printing cathode ray tube **59,** and via lines **57** and **59A** to the raster shaper **62** for the left scanner camera, and via lines **57** and **60** to the raster shaper **63** for the right scanner camera. Scanning reference signals are delivered via lines **57** and **61** to the correlator **49.**

The raster shapers **62** and **63** both receive ΔZ signals from the correlator **49** along lines **64** and **65.** Raster shapers **62** and **63** also receive signals from computer **29** along lines **66** and **67** respectively.

The raster shapers **62** and **63** modify the square raster wave forms from the scan generator delivered on lines **59A** and **60** to produce raster wave forms on lines **66A** and **67A** that produce in scanners **25** and **26** rasters that are distorted by high order transformations from their normal square shape. By this means the left and right stereo images are transformed in such a manner that the video signals on lines **50** and **51** become more similar, and the image in the scanning printer **43** reflects the corrections for scale and other distortions arising out of nonorthogonal conditions when the pictures were taken.

A parallel line or TV scanning pattern can be conveniently used in the system of the present invention. The scanning lines run parallel to the X axis of the model so that the X parallax may be detected simply by means of timing differences between the left and right video signals. The number of transformation elements, i.e., measurements of time differences in the raster, is dictated by the degree of distortion or transformation that must be applied to accommodate terrain irregularities. The transformation degree that can be achieved is very high, e.g., equivalent to that of a 50th-order system, and is not a limiting fastor to raster size. The number of transformation elements, the size of the raster, and the video information content of the raster are a function of the precision with which the scanning rasters can be controlled. Various system parameters can be adjusted to optimize precision-limitations. If a standard scanning raster is used, then the magnification from the film plane to the scanning raster can be selected to optimize the system resolution. A raster conforming to American TV standards is convenient for the subject invention.

The American TV (RETMA) raster parameters referred to are as follows:

Line period = 63.5 microseconds

Field period = 1/60 second

Single interlace with two fields per frame, and thus a frame period = 1/30 second

Aspect ratio width/height = ¾.

The ends of the raster can be masked to provide a square format.

Although the scanners **41, 42** and scanning printer **43** are shown to include vidicons and a cathode ray tube, they also may comprise flying scanners well known in the art.

Present aerial photographs have a resolution of about 20 line pairs/mm or 1,600 resolution elements per square millimeter. A 320 × 320 resolution element raster at photo scale would thus be 8 mm square, 8 mm also being convenient for the subject invention with the optical system of the scanners being chosen appropriately to match the film to the pickup system. Since the overlap or model area of the diapositives is approximately 100 × 220 mm, i.e., 22,000 square mm total, it will be seen that the scanners will scan only a small portion of the overlap at any instant and that 22,000/64 or approximately 350 patches of raster size must be investigated to produce a complete orthophotograph of the model area.

Owing to the absence of adequate transformation means in prior art systems for adjusting the scan raster of the scanners, such orthophoto printers using the patch method of printing have been forced to employ a patch area of less than about 1 square mm in order to avoid visible discontinuities between adjacent patches. This small patch size has seriously restricted the speed of operation of such instruments. However, using the teachings of the present invention for image transformation, a patch size of greater than 8 mm square at photo scale is made possible, and hence a much higher speed of operation can be obtained than has been possible hitherto.

A preferred embodiment of the printer **43** is shown in more detail in FIGS. 2–4. The positioning mechanism of this device is described and claimed in more detail in my copending application entitled "Photo Positioning Device," Ser. No. 44,305, filed June 8, 1970, now U.S. Pat. No. 3,687,547 which is also assigned to the assignee of the present invention.

A frame assembly **70** is adapted to hold the photographic film **43A**, whose emulsion is to be exposed to the orthophotograph. The frame assembly **70** rests upon a flat base assembly which includes a plate **71** and is provided with a suitable surface to provide easy movement of the frame **70** across the plate **71**. Bearing feet or pads have been used on the underside of one frame assembly **70** and were found to work well. A pair of geared driving racks **72** and **73** each carry at one end thereof a frame engaging end member **74, 75**, respectively. Members **74** and **75** each carry a pair of rollers **76** which rotate about horizontal axes and ride on the upper surface of the plate **71**. Second pairs of rollers **77** supported for rotation about a vertical axes and each of the members **74** and **75** engage the edges **102, 103** of the frame assembly **70**. The outer ends of the racks **72, 73** are supported by rollers **78**. The edges **102, 103** of the frame assembly **70** are flat surfaces which intersect at an angle of 90° for the particular system illustrated herein. The racks **72** and **73** are maintained perpendicular to the surfaces **102** and **103** and therefore the racks, if extended, would intersect at an angle of 90°.

The frame **70** is maintained in engagement with each of the rollers **77** by any suitable assembly. In the preferred embodiment, the opposite corners **79, 80** of the frame **70** have the ends of cables **81** and **82** secured thereto. Cable **82** passes around a guide **83** supported on plate **71**, and then around guide **84** also supported on plate **71**. In a similar manner, the cable **81** passes around the guide **84**. Two cables extend from guide **84** around a guide **85** supported for rotation about a horizontal support located in the plane of the plate **71**, through an opening in the plate **71** adjacent guide **85**, and around a pulley **86** having a weight **87** secured thereto. Through pulley **86**, the cables extend through an opening, not illustrated, in plate **71**, around an adjustment eccentric **88**, and are secured by their respective ends to clamps **89** attached to the plate **71**. The arrangement is such that the weight **87** acting through the cables **81** and **82** provides a yielding force to the frame **70** which arches the edges **102** and **103** into engagement with the rollers **77** associated with drive racks **72** and **73**. Rotation of the eccentric **88** is used for initial adjustment of the cables.

A drive gear **91** secured to the drive shaft of a reversible electric motor **46B** engages the rack **72**. In a similar manner, a drive gear **112** secured to the drive shaft of a second reversible electric motor **46A** engages the drive rack **73**. The operation of the reversible electric step motors **46A, 46B** is interrupted by operation of an associated control switch by arms **93, 111** having rollers **94** and **112** engaged with the non-toothed edge of the associated racks **72** or **73**. The arms **93** and **111** are pivoted on pins secured to the plate **71**. The switches **97** and **113** associated with the arms **93** and **111** are adapted to be operated whenever the respective arm is moved clockwise. The end members **74** and **75** on the racks **72** and **73** have beveled surfaces, such as surface **92** on member **74**, which engage the rollers **94** and **112** whenever the racks reach their maximum extent of outward movement. Therefore, the associated switch **97** or **113** will be actuated to interrupt further drive of the rack. Corresponding beveled surfaces, such as surface **92A** on rack **72**, on the outer ends of the racks **72** and **73** serve the same purpose when the maximum extent of inward travel has been reached.

As seen in FIGS. 2 and 4, a lens **101** is aligned with the intersection of the lines of travel of racks **72** and **73** so that the center of printing corresponds to this intersection. More specifically, this intersection occurs at the intersection of the pitch lines of the drive racks **72** and **73**.

The film **43A** can be held in position in the frame **70** by various means. For purposes of illustration, the film **43A** is secured to a backing plate **70A**. A corner stay **98** is shown as being in engagement with one corner of the plate **70A** with springs **99, 100** urging the corner stay **98** and plate **70A** towards the opposite corner of the frame **70**.

The orthphotograph is constructed by first establishing a pair of model coordinates within the computer **29**, then delivering stage coordinate signals via lines **46X, 46Y** to the motors **46B, 46A** of the printer **43**, so as to cause the frame **70**, and therefore the film **43A**, to assume a position with respect to the optical center lens **101** corresponding to the selected model coordinates. At this point in time, the cathode ray tube **59** is blanked by the inhibit signal appearing on line **56A**. Subsequently, the computer causes the scanners **25** and **26** to reduce the center-point X parallax to an acceptable level and causes the scanner transports to reduce the Y parallax to zero by movements in response to stage coordinate signals delivered on lines **44X, 44Y, 45X, 45Y**. Thereafter, the higher order X parallax is reduced to zero in response to signals from the correlator **49**, and subsequent operation of the raster shapers **62** and **63**.

When X parallax and other errors are eliminated, the inhibit signal is removed from line **56A** and the video output of either scanner **25** or **26**, as determined by the left-right signal on line **55A**, is coupled via line **55** to the cathode ray tube **59**. Accordingly, the corrected video signal appears as an image **104** on the face of the scanner **59**. This image **104** will be coupled through the lens **101** to expose a portion of the film **43A**. After exposure is complete, the computer **29** selects new model coordinates and delivers appropriate stage coordinate signals via lines **46X, 46Y**, so that the printer **43** assumes a new position. Thereafter, the cycle is repeated.

When the entire overlap area of the stereo photographs has been treated, the orthophotograph appears, as in FIG. 5, to comprise a plurality of adjacent, square patches **110**.

If each of the patches **110** reproduces its corresponding correlation zone with absolute fidelity, and if the patches **110** are precisely aligned with each other, the boundaries between patches would be practically indistinguishable. However, errors in alignment do occur, despite the use of a precise and accurate plotting device such as illustrated in FIG. **2.** The aforementioned difficulties of obtaining a uniform, non-distorted trace on a cathode ray tube contribute to distortions in position as well as light intensity at the extremities of each patch. Accordingly, the boundaries between adjacent patches often appear as a plurality of vertical and horizontal lines, **111, 112.**

Although in most cases these lines are but mildly distracting, they become of significance when they coincide with an important feature of the orthophotograph. For example, the vertical line **111A** in FIG. **5** tends to obscure a portion of a runway **113** depicted therein. This distortion may materially lessen the value of the orthophotograph in cartographic applications, wherein very accurate detail is required.

Accordingly, the method of the invention allows construction of an orthophotograph by a hexagonal patch.

With reference now back to FIGS. **2–4,** a plate **106** includes a plurality of apertures **107** for receiving a corresponding plurality of pins **105** which are secured in plate **71.** Plate **106** also defines a centrally-located, hexagonal aperture **108** whose area corresponds to a desired area of each patch making up a composite orthophotograph. The plate **106** is generally positioned so as to align the center of aperture **108** with the center of optics **101.** Therefore, the hex patch which is printed is centered on the image **104** reproduced by CRT **59.**

To construct the orthophotograph, the model coordinates are selected by the computer **29** so that the frame **70** is first moved in uniform increments along the Y axis until the Y-dimension of the orthophotograph has been traversed. Then, the X model coordinate is moved by an appropriate increment, and the Y model coordinate is moved by an increment that is out of phase with the adjacent Y coordinate in a direction opposite to that previously traversed. Printing thereafter proceeds in uniform increments along the Y axis in the opposite direction until the Y-dimension is again traversed, at which time the cycle is repeated. The X and Y increments should be chosen in view of the dimensions of hexagonal aperture **8** so that adjacent patches are juxtaposed.

A resultant composite orthophotograph is seen to comprise, in FIG. **6,** a plurality of adjacent, hexagonal patches **114.** Although problems of patch misalignment may still occur, the tracing errors occurring at the edges of the image **104** are reduced due to the masking effect of plate **106.** More important, misalignment and tracing error are much less apparent in the orthophotograph of FIG. **6,** in that there are no continuous straight lines extending across the photograph for the observer's eye to follow. In addition, important features of the overlap area are not obliterated, as might be in the case using a rectangular patch such as in FIG. **5.**

Because inaccuracies may yet arise from CRT tracing error and from the difficulty of effecting a complete transformation over a given overlap area, the size of the hexagonal aperture **108** may be varied to allow more precision and accuracy in the composite orthophotograph. Accordingly, a number of plates **106** may be provided, each having a different-sized hexagonal aperture **108.** As the aperture size is changed, the programmed model coordinates in the computer **29** must also be changed to assure accurate spacing of the patches **114.**

While this invention has been described with reference to a preferred embodiment thereof, it is to be clearly understood by those skilled in the art that the invention is not limited thereto, but rather is intended to be bounded only by the limits of the appended claims.

What is claimed is:

1. A method for printing an orthophotograph from the overlap area of a pair of stero photographs onto a sensitized film, comprising the steps of scanning a patch on each of said pair of stereo photographs about a point established by a predetermined set of model coordinates, each patch comprising a portion of said overlap area representing homologous areas of said pair of stereo photographs, providing an image from said scanning which corresponds to said homologous areas and which is compensated for parallax and other distortion errors, masking the edges of said image to provide a hexagonal image, and exposing a portion of the sensitized film to said hexagonal image, further comprising the steps of repeatedly modifying said set of model coordinates by predetermined increments, and correspondingly adjusting said areas of scanning and the relative positions of said sensitized film and said hexagonal image so that adjacent patches of said pair of stereo photographs are successfully investigated and printed.

2. In an orthophoto printing system comprising in combination a photo positioning means for holding first and second photographs making up a stereo pair, a scanner means including first and second scanners aligned with said photographs and each including raster signal means for controlling scanning of a selected patch on each photograph, each patch being an area of a photograph covered in one complete scan cycle with the scan pattern for each scan cycle being a plurality of adjacent parallel scan lines, a printing means including a scanning display means and means holding a segment of sensitized film in alignment with said scanning display means, said scanning display means including means providing an image corresponding to the undisturbed scan pattern of one of said vidicons for the exposure of a patch of film made up of a plurality of adjacent lines, means connecting said scanning display means with said scanner means to render said scanning display means under the control of signal information derived from said scanner means, signal correlating means coupled with said scanner means and operative to derive error signals proportional to the timing differences between homologous components of the video signals provided by said first and second scanners, means connecting said correlating means to said raster signal means in response to said error signals to alter the scan pattern for at least one of said first and second scanners, and signal memory means connected between said correlating means and said raster signal means for storing the error signals derived from a complete area being scanned by said scanner means, said signal storage means providing output signals to control the alteration of the raster of at least said one of said scanners during the operation of said scanning display means with the image for said scanning display means remaining the same as an undisturbed scan pattern of one of said scanners, an improvement in said printing means comprising means defining a hexagonal aperture, said means being interposed between said scanning display means and said sensitized film for masking the edges of said image of said scanning display means, to reproduce on said sensitized film a hexagonal patch corresponding to a portion of said undisturbed scan pattern of one of said vidicons.

3. The improvement as recited in claim **2,** further comprising means repeatedly moving said photographs and said sensitized film with respect to said scanner means and said scanning display means, respectively, in predetermined increments dependent in part on the size of said hexagonal aperture, said movements being effected after the completion of each raster alteration caused by said signal storage means.

4. The improvement as recited in claim **3,** further comprising means blanking said scanning display means until the completion of each raster alteration caused by said signal storage means.

5. An automatic orthophoto printing system, comprising means for providing a video signal from a pair of stereo photographs which corresponds to patches thereof representing homologous areas in a portion of the total area of said stereo photographs and which is compensated for parallax and other visual distortion errors, a scanning display means for displaying an image corresponding to said video signal, means masking said image to produce a hexagonal image, means exposing a sensitized film to said hexagonal image, a photo positioning means for adjusting the relative position of said hexagonal image displayed on said scanning display means in said sensitized film, and further including means for repeatedly moving the centers of said patches and the relative positions of said sensitized film and hexagonal image in discrete increments to construct an orthophotograph.

6. A system as recited in claim **5,** wherein said scanning display means comprises a cathode ray tube.

7. A system as recited in claim **5,** wherein said scanning display means comprises a flying spot scanner.

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