United States Patent [19]

Jones

[11] **3,737,229**

[45] **June 5, 1973**

[54] **RELIEF PHOTOGRAPH CONVERSION PRINTING APPARATUS**

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[21] Appl. No.: **649,312**

[52] **U.S. Cl.** **355/78**
[51] **Int. Cl.** **G03b 27/02**
[58] **Field of Search** 355/33, 78; 95/18

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Attorney—Robert E. Isner, Peter J. Franco and Spencer T. Smith

[57] **ABSTRACT**

Photographic printing method and apparatus for converting abnormal, reversed or pseudoscopic three-dimensional photographic images to normal images concurrently with the printing thereof in desired size relation through interposition use of multielement lens overlays to effect selective optical inversion of component image elements and exposure of photosensitive film to such inverted relief data images.

4 Claims, 14 Drawing Figures

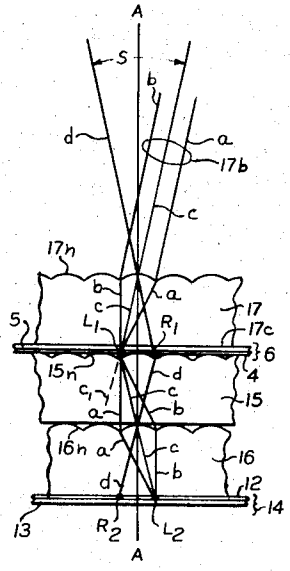


FIG. 1.
PRIOR ART

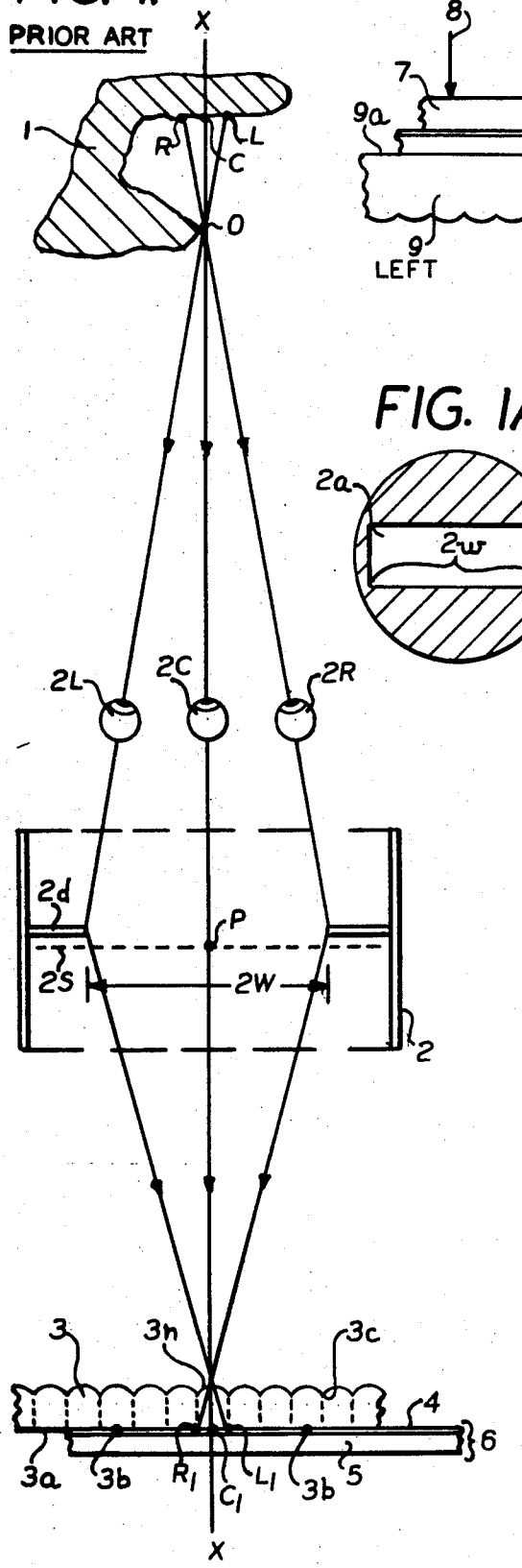


FIG. 2.

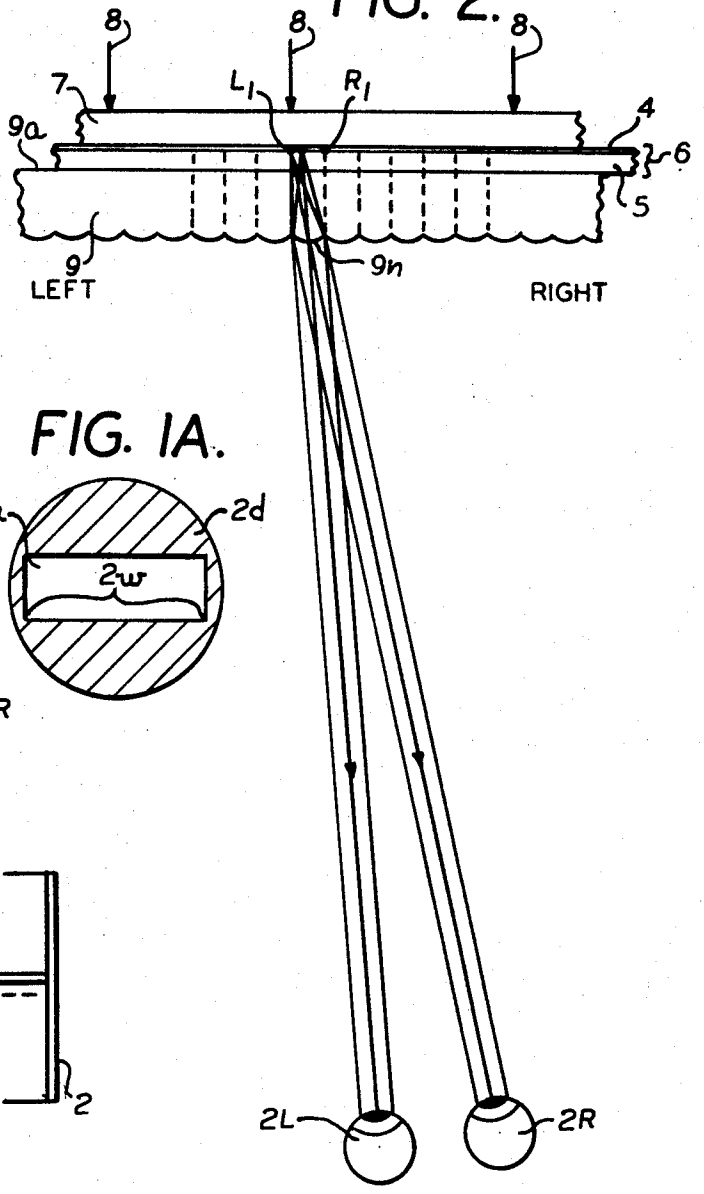


FIG. 1A.

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FIG. 3

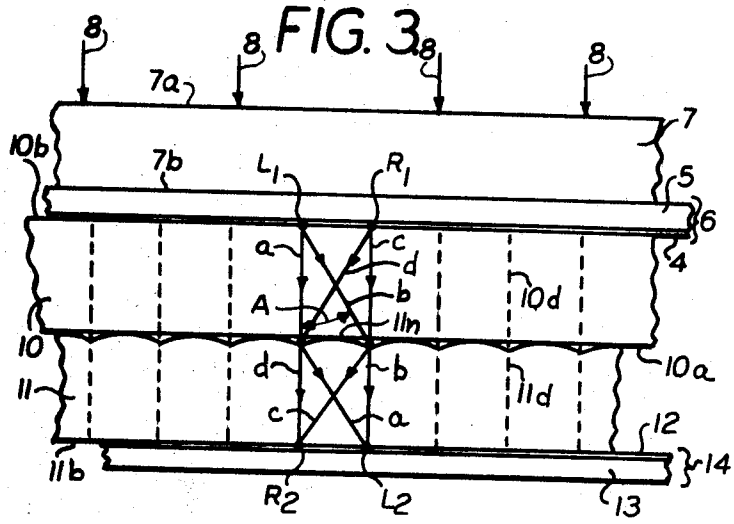


FIG. 3A.

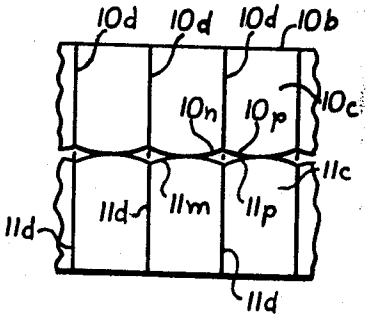


FIG. 4.

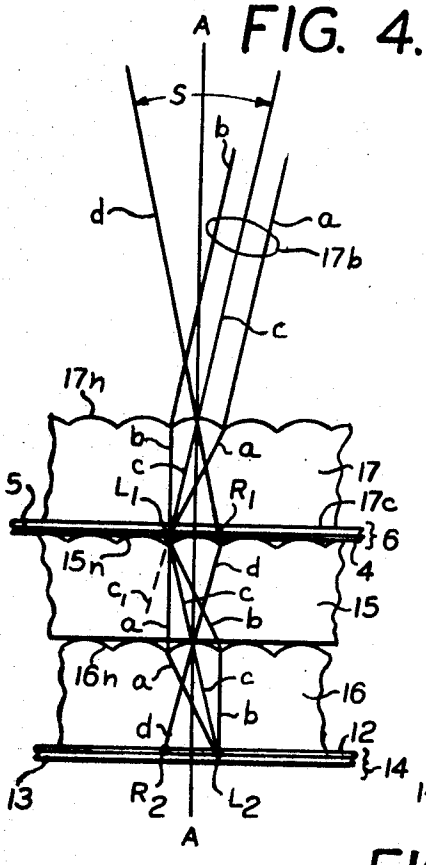


FIG. 4B.

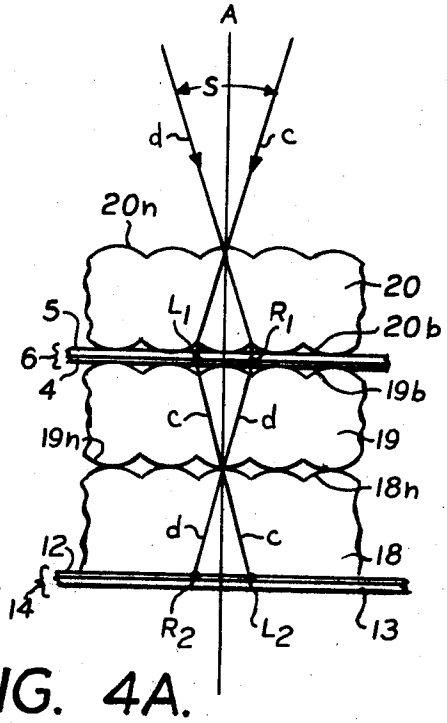
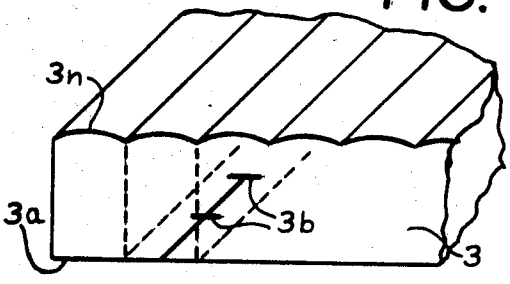


FIG. 4A.



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FIG. 5.

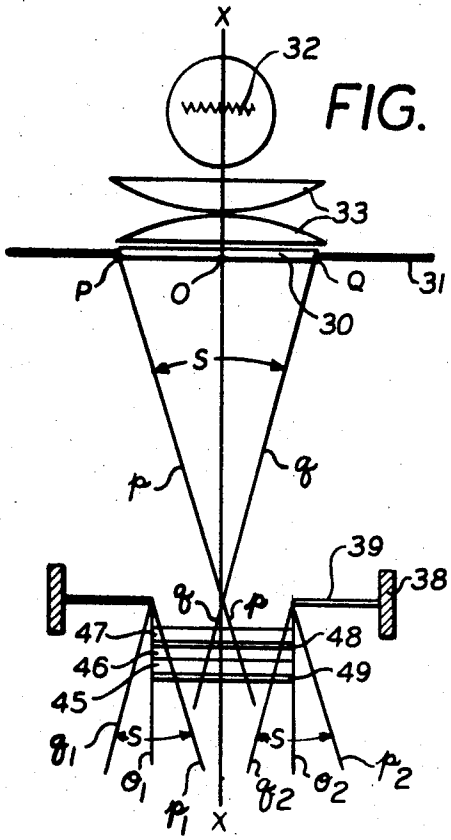


FIG. 7.

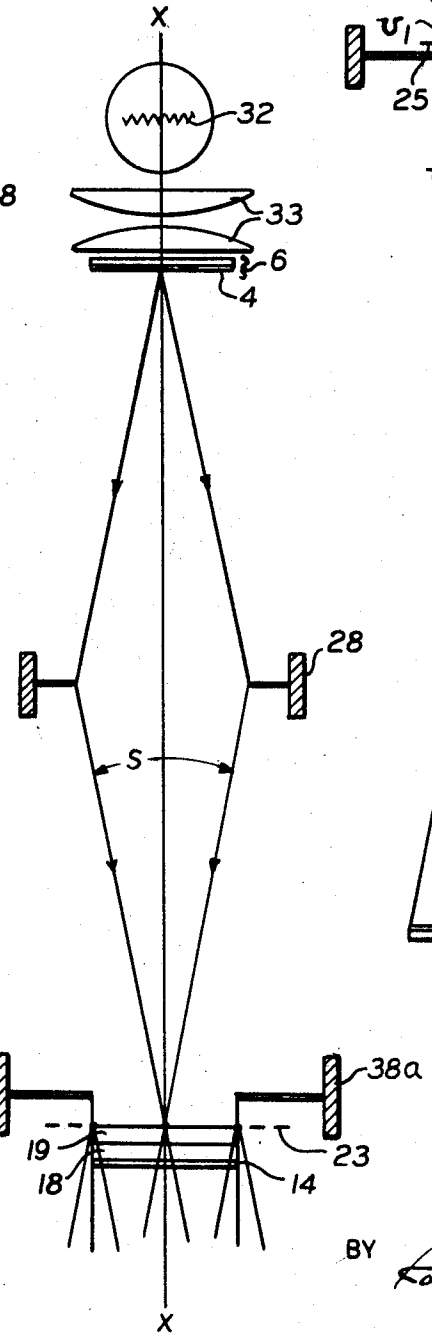


FIG. 9.

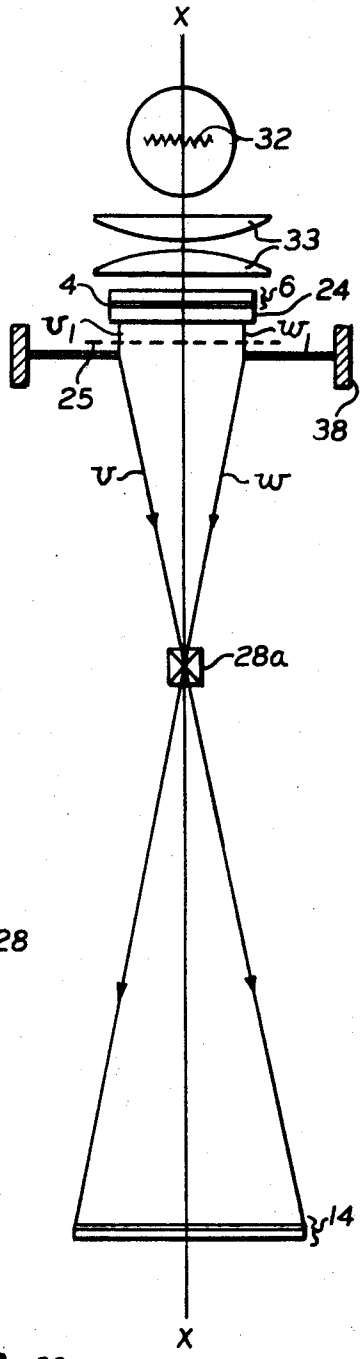
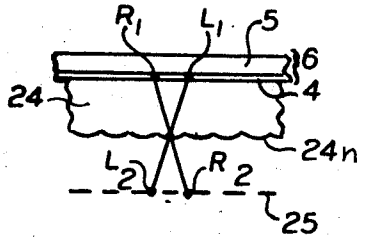


FIG. 8.



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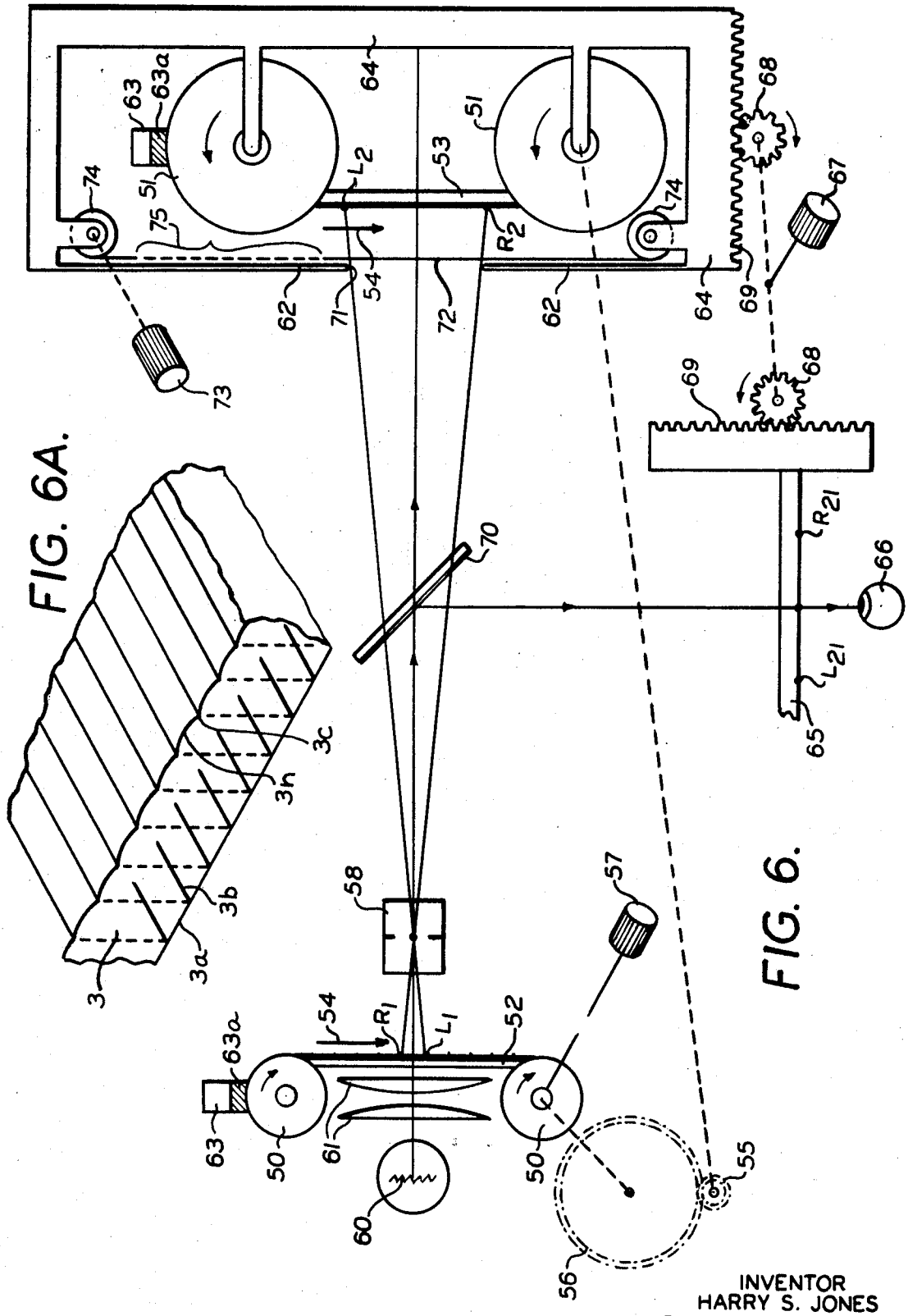


FIG. 6A.

FIG. 6.

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RELIEF PHOTOGRAPH CONVERSION PRINTING APPARATUS

This invention relates to relief photography and particularly to an improved method of converting abnormal three-dimensional or relief photographic images into normal relief reproductions thereof.

The obtaining of relief or three-dimensional images or effects in the photographic arts has, for many years, challenged the skilled workers in this field. While the basic theory and the nature of the problems involved have long been known and understood, the present day dearth of simple, commercially practical and inexpensive relief photographs and methods of obtaining the same cogently demonstrate the continued inability of the art to solve the problems involved.

The prior efforts in this field reveal both simple and complicated systems having various advantages and limitations and which are divisible into three general classes. The first of these involves the taking of two photographs of a subject using one or two camera lenses located at two different positions relative to the subject. Such photographs are usually referred to as a stereo pair.

The second class obtained the relief effect essentially by the taking, through a single lens, of a continuous series of photographs of the subject, as viewed from a continuous series of positions and recording the series through an array of very small auxiliary lenses or apertures located very close to the photographic film plane so that an image of the single lens aperture is focused upon the film by each of such auxiliary lenses or apertures. The third broad class involves the use of a lens of very large diameter in association with a grating or lenticular system disposed intermediate the objective and the film plane.

This invention may be briefly described as a method of converting abnormal relief or three-dimensional photographic images into normal or true three-dimensional reproductions of the photographed subject and in its broad aspects includes an improved method of printing by which the abnormal images that are usually attendant the use of simplified apparatus of the third class referred to above are converted into true or normal relief photographic representations of the image subject when viewed with a single layer of lenticular elements disposed adjacent to the film plane.

As used herein, an "abnormal" relief or three-dimensional image will be one in which, as the viewer's head is moved to the right, the left side of the subject (i.e., relative to the viewer's left hand) will be increasingly revealed in contradistinction to the normal appearance of any subject in which, as the viewer's head is moved to the right, the right side of the subject (i.e., relative to the viewer's right hand) is increasingly revealed.

The primary object of this invention is the provision of an improved photographic printing method for the conversion of abnormal relief photographic images to normal three-dimensional representations of the image subject.

Other objects and advantages of the invention will be apparent from the following portions of this specification and from the accompanying drawings which illustrate the principles of this invention and the incorporation of such principles into a presently preferred embodiment thereof.

Referring to the drawings:

FIG. 1 is a schematic representation of the essentials of a simple photographic system employing the full lens aperture width of a large lens for relief photographic effects.

FIG. 1A is an axial view of a lens aperture configuration suitable for use in the system of FIG. 1.

FIG. 2 is a schematic representation of one relief image assembly that results from the photographic technique incorporated in FIG. 1.

FIG. 3 is a schematic representation of one means by which an abnormal relief image may be converted into a normal or true three-dimensional representation thereof in accordance with the principles of this invention.

FIG. 3A is a schematic representation of one means for the elimination of light scattering when using the abnormal to normal image conversion system of FIG. 3.

FIG. 4 is a schematic representation of an alternate means for the elimination of light scattering during the abnormal to normal image conversion operation.

FIG. 4A is a perspective illustration of one form of alignment mark which may be applied to multiple lens arrays of the type used in the practice of this invention.

FIG. 4B is a schematic representation of a portion of a preferred alternate means for the elimination of light scattering during the abnormal to normal image conversion operation.

FIG. 5 is a schematic representation of one means by which the special illumination needed for operation of the systems shown in FIGS. 4 and 4B may be produced.

FIG. 6 is a diagrammatic representation of apparatus for effecting enlargement and/or reduction of images concurrently with the conversion of abnormal relief images in accordance with the principles of this invention.

FIG. 6A is a schematic fragmentary perspective representation of a lens overlay element and markings thereon.

FIG. 7 is a schematic representation of a further construction for effecting abnormal to normal image conversion.

FIG. 8 is an enlarged fragmentary view of a portion of the enlargement and conversion system illustrated in FIG. 9; and

FIG. 9 is a schematic representation of a modified construction for effecting conversion and enlargement of three-dimensional photographic images.

Referring to the drawings and particularly to FIGS. 1 and 1A, the essentials of the simplified camera system of the third class referred to above for obtaining relief photographic effects include a lens assembly incorporating a large aperture camera lens 2 and an associated aperture plate 2*d* whose aperture 2*a* constitutes a horizontally-disposed rectangle of a width 2*w* that is normally comparable with the spacing between the human eyes. In FIG. 1 the actual glass lens elements have been omitted for the purpose of simplicity and clarity. The lens 2 and aperture width 2*w* may be larger than that noted for exaggerative three-dimensional effects or smaller when a small subJect is to be photographed. In order to obtain a three-dimensional photographic image of a subject all that is essentially required is to utilize the rectangular aperture 2*a* at the stop plane of camera lens 2 and to project the image of a subject 1 onto a perpendicularly oriented cylindrical lens overlay 3 of transparent glass or plastic having a large number of small cylindrical lens surfaces 3*n* on

the upper surface thereof and having film **6** positioned adjacent the undersurface thereof. When the film **6** is exposed by means of any suitable shutter located in a plane **2***s* close to aperture **2***a*, a three-dimensional photographic image of a subject **1** may be taken. As will be apparent from the drawing, points O and C on subject **1** located on the optical axis X—X will be imaged on the film emulsion **4** on the axis X—X at point C_1. Similarly, points O and R will be imaged at point R_1 on the film emulsion **4** and points O and L will be imaged at point L_1 thereon. It should be noted that image point R_1 corresponds to points O and R as seen by a right eye **2**R and image point L_1 corresponds to points O and L as seen by a left eye **2**L. A single eye **2**C located between will see only points O and C. As is known to those skilled in this art, the purpose of any particular cylindrical lens element **3***n* of the cylindrical lens overlay **3** is to form an image of aperture **2***a* on the film emulsion **4.** Preferably, the width of the aperture image formed by an individual cylindrical element **3***n* shall be the same as the width of each cylindrical lens element **3***n*, that is, equal to the distance between R_1 and L_1.

Referring now to FIG. **2,** when the film **6** of FIG. **1,** after exposure as outlined above, is processed to transparency form, a cylindrical lens overlay **9** having cylindrical lens elements **9***n* of the same width as employed in the overlay **3** which was used during exposure must be placed closely adjacent to the film in order to produce an observable three-dimensional or relief effect. Such lens overlay **9** is placed over the transparency **6** (or a positive print of the same size) against the side opposite from emulsion side **4** with the lens axes thereof disposed parallel and coincident with those of lens overlay **3** employed during exposure. When provision is made for either front or back illumination of the image, a normal top-side-up, right-side-right image of the photographed subject will be obtained if the photograph is turned as shown in FIG. **2** so that points L_1 and R_1 are the same points shown in FIG. **1.** An opaque diffusing screen **7** is preferably employed to utilize light rays **8** for back illumination of transparency **6.** However, the three-dimensional characteristics of this image will be abnormal, in that as the viewer's head is moved to the right, the left side of the subject's image (relative to the viewer's left hand) will be increasingly revealed, rather than the right side thereof. This is opposite from the normal image appearance of solid objects in which the right side thereof (relative to the viewer's right hand) is increasingly revealed as the viewer's head is moved to the right.

Even if the transparency **6** is turned about a vertical axis so that its emulsion side **4** is in contact with the lens overlay **9,** the image will still exhibit abnormal three-dimensional characteristics. When so located, the image will still be top-side up but the left and right portions thereof will be reversed. As a practical matter, in the use of a simplified camera apparatus of the type shown in FIG. **1,** there exists no possible orientation of transparency **6** or positioning thereof relative to the necessary lens overlay **9** in which the viewed image will appear both right-side right, top-side-up and be possessed of normal three-dimensional characteristics, even if one or more plane mirrors, or dove or Wallaston prisms are used to reverse the image about horizontal and/or vertical axes.

As pointed out above, the image formed on the emulsion **4** of the film **6** in a camera of the FIG. **1** type will, after processing, yield an abnormal transparency or negative, insofar as its relief characteristics are concerned.

Referring now to FIG. **3,** the emulsion side **4** of the film or transparency **6** exposed as described above in conjunction with FIG. **1** is disposed in abutting interfacial relationship against the flat surface **10***b* of a transparent spacer element **10.** Disposed in abutting interfacial relationship with the other surface **10***a* thereof are the cylindrical lens elements **11***n* of a cylindrical lens overlay **11** made of transparent glass or plastic. The emulsion side **12** of a second film **14** is disposed in abutting interfacial relation with the optically flat undersurface **11***b* of the lens overlay **11.** Illumination is effected by light rays **8** diffused by element **7** having flat surfaces **7***a* and **7***b*.

As will be apparent, as indicated by rays *a* and *b* which are disposed between points L_1 and L_2 and rays *c* and *d* which are disposed between points R_1 and R_2, the above described arrangement effects the inverse transfer of points R_1 and L_1 on film or transparency **6** to points R_2 and L_2 on the second film **14.** Essentially, the above is similar to simple contact printing of transparency **6** on film **14** to produce a corrected transparency **14** after processing thereof. However, due to the action of the included cylindrical lens overlay **11,** the points R_1 and L_1 and all points in between will be properly printed in reverse order on film **14.** As indicated by the drawing, the curvature of cylindrical lens surfaces **11***n* of lens array **11,** the refractive indices of the material employed in lens array **11** and in the transparent spacer **10** and the thicknesses of elements **10** and **11** are selected so that each lens surface **11***n* focuses an image of all points located on line R_1L_1 on transparency **6** upon all points on line R_2L_2 on film **14.** Likewise, the thicknesses of the spacer element **10** and the cylindrical lens array **11** are selected so that the spacing between R_1 and L_1 on film **6** is the same as that between R_2 and L_2 on film **14** and thereby corresponding to a magnification of unity by the lens formed by curved surface **11***n* and flat surface **10***a*. When film **14** is exposed as described above and is processed it will appear in normal relief when a cylindrical lens array that is similar to the lens array **3** used to expose the original film **6** is placed with its flat side in contact with the emulsion side **12.** The corrected relief image will also appear with normal top-side-up and right-side-right characteristics when the film is properly oriented.

As will now also be apparent, the emulsion sides of film **6** and/or film **14** may also be placed so that they do not face lens elements **11***n*. If, when so disposed, the film thickness is such as to constitute a substantial fraction of the thickness of spacer **10** and lens array **11** it may be found necessary to utilize a differing curvature for lens element **11***n* or differing thickness of elements **10** and **11** to insure sufficiently sharp focus of the line R_2L_2.

The spacer element **10** and cylindrical lens array **11** shown in FIG. **3** may, if desired, be replaced by a pair of cylindrical lens overlays **10***c* and **11***c* as shown in FIG. **3A.** As there illustrated, the lens overlays are preferably identical and have cylindrical lens elements **10***n* and **11***m* disposed in facing relation and with each other, each such lens element being of approximately double the radius of each individual lens element **11***n* of FIG. **3.**

Since in actual use stray light tends to spread to adjacent elements of the over-all picture, low-reflective opaque barriers **10***d* and **11***d* may be included between each individual lens element to absorb such stray light as shown in FIG. **3**A. Such light baffling surfaces **10***d* may also be included in both the spacer and lens elements **10** and **11** of the correcting system shown in FIG. **3** and preferably, these barriers should abut each other so that no light may pass between adjacent lens elements such as **10***n* and **11***m* and **10***p* and **11***p* in FIG. **3**A.

When desired, an image of the original film **6** may be used in lieu of the actual film as by projecting such image upon a ground-glass or equivalent type screen. Such a ground-glass surface should be placed with its ground surface in contact with surface **10***b* of the FIG. **3** and **3**A systems. Each relief data strip $R_1 - L_1$ in the image of film **6** must, of course, be axially aligned with such lens element as in the foregoing systems.

FIG. **4** illustrates the essentials of a somewhat more sophisticated form of multiple lens array which, in conjunction with an associated illumination system, will reverse-print an abnormal three-dimensional transparency or negative in substantially the same manner as that shown in FIGS. **3** and **3**A and described above, but which effectively dispenses with any need for opaque light barriers between the individual lens elements. Essentially, the spacer and lens overlay elements **10** and **11**, respectively, of the FIG. **3** construction are replaced by a pair of lens overlay elements **15** and **16**, respectively, and wherein lens overlay **16** functions in a manner substantially identical with that of lens overlay **11**. In contradistinction thereto, lens overlay **15** is provided with lenticulations **15***n* that are substantially identical with those of lenticulations **16***n* and which are disposed in contact with the emulsion side **4** of film **6**. A third lens overlay **17** is placed with its flat undersurface **17***c* in contact with the uncoated surface **5** of film **6**. All of the individual lenticulations on lens elements **15, 16** and **17** are disposed so that their optical axes coincide with a vertical line or plane, as indicated by line A—A.

By way of explanatory example, three dimensional data points from L_1 to R_1 on film **6** will be printed in reverse order from points L_2 to R_2 on the emulsion surface **12** of the second film **14** as in the system heretofore described in connection with FIG. **3**. However, due to the action of lenticulations **15***n* and **17***n* the component rays *a*, *b* and *c* of a substantially parallel ray bundle generally designated **17***b*, are refracted and effectively confined to the lens elements disposed along axis A—A and, hence, are prevented from spreading to adjacent elements as would a theoretical ray such as shown by the dotted line *c*1. In such a system as that described it will now be apparent that if the total illumination used for printing the entire photograph provides parallel light within a suitable maximum angle S over the entire area, line $L_1 - R_1$ will be reverse-printed along line $L_2 - R_2$. All other three-dimensional data points on film **6** under all other lens elements **17***n* of lens array **17** will be similarly reverse-printed to form an exposure in normal relief on film **14** without loss of detail or fogging due to spreading of stray light between adjacent lens elements. The curvature of lens overlay elements **15***n*, **16***n* and **17***n*, the thickness of and the refractive indices of lens overlay elements **15, 16** and **17** must, of course, be chosen so that line $L_1 - R_1$ will be focused upon line $L_2 - R_2$ with a magnification of unity.

In order to align the three-dimensional or relief image data recorded on film **6** in relation to lens array **17** in a manner identical with its original relation to the camera lens overlay **3** as shown in FIG. **1**, any suitable lines or marks, such as indicated at **3***b* in FIG. **4**A may be provided on the flat undersurface **3***a* of lens overlay **3**. A similar mark provided on the flat undersurface **17***c* of lens overlay **17** (or on the lenticulations **20***n* of lens array **20** in FIG. **4**B) could then be used for visual alignment purposes prior to printing as already described. Such markings used for alignment should, of course, be located close to the edge of the film in order not to degrade the appearance of the subject.

A modified construction of the printing arrangement illustrated in FIG. **4** is shown in FIG. **4**B wherein lens overlays **16, 15** and **17** are replaced by lens overlays **18, 19** and **20**, respectively, in their relation to film **6** and to film **14**. The curvature of individual lens elements **18***n*, **19***n* and **20***n* and of individual lens elements **19***b* and **20***b* may all be identical to simplify construction. Lens overlay elements **18, 19** and **20** may be of the same thickness and elements **19** and **20** may, therefore, be identical elements. The reverse-printing of line $L_1 - R_1$ upon $L_2 - R_2$ with unity magnification and all other relationships will also be the same as in the system shown in FIG. **4**. The facing lens surfaces **19***b* and **20***b* function jointly in a manner similar to single surface **15***n* in FIG. **4**, while facing lens surfaces **18***n* and **19***n* function jointly in a manner similar to single surface **16**n in FIG. **4**. In this embodiment only illustrative rays *c* and *d* have been shown in order to simplify the diagram.

A modified unit may be constituted by replacing the lens overlay element **20** of the FIG. **4**B construction by a diffusing plate of the type illustrated in FIG. **3**. When so arranged and when the diffusing plate is properly illuminated, an abnormal film **6** will be correctly printed on the film **14** as a normal relief image with greatly reduced fogging due to the focussing action of lens elements **19***b* which reduces the stray light existing in the system of FIG. **3**.

As mentioned earlier, use of the FIG. **4** and **4**A system requires selective illumination. A simple and presently preferred means for providing the necessary illumination is set forth in FIG. **5**. As there shown, a diffusing plate **30** constructed of ground or opal glass carried by an opaque support **31** is conventionally illuminated by a tungsten or other suitable light source **32** via condensing lenses **33**. A lens **38** having a stop plane **39** is located so that its object focal plane coincides with the plane of diffusing disc **30**. Lens **38** will, therefore, act to collimate light rays from a point O on the diffusing plate **30** on the common optical axis X—X as a parallel ray bundle similar to ray bundle **17***b* of FIG. **4**; the edges of which contain parallel rays o_1 and o_2. Similarly, rays from a point P on diffusing plate **30** will be collimated as a parallel ray bundle, the edges of which will contain parallel rays p_1 and p_2. Similarly, rays from a point Q on diffusing plate **30** will generate a parallel ray bundle, the edges of which will contain parallel rays q_1 and q_2. If the size of the ray bundle $o_1 - o_2$ is somewhat larger than the size of multiple lens overlay arrays **45, 46** and **47** and films **48** and **49** and if the angle S, as determined by the size of plate **30** and the focal length of lens **38** is equal to the angle S delineated in FIGS. **4** and **4**B, it will be clear that the described illumination sys-

tem will provide the desired type of illumination required for the printing systems shown in FIGS. 4 and 4B. To utilize such an illumination system for correction of abnormal relief photographs, it is therefore only necessary to place the correcting stack, comprising film elements **48**, and **49** and lens elements **45, 46** and **47** as close as possible to lens **38.** In FIG. **5,** the actual glass lens elements constituting lens **38** and the small lens elements of lens overlay arrays **45, 46** and **47** have been omitted for simplicity and clarity.

If diffusing plate **30** is of suitable size and shape, preferably circular or hexagonal, the system described above will be suitable for use with lens arrays having spherical lenticulations. For cylindrical lenticulations the diffusing plate **30** may be made rectangular, preferably with a ratio of length-to-width of at least two-to-one, in order to retain the usually greater image resolution in the direction parallel with the axes of the cylindrical lenses. The long dimension of such a rectangular diffusing plate should, of course, be perpendicular to the direction of the axes of the cylindrical lens elements.

It should also be clear that, when desired and as disclosed in my copending application Ser. No. 649,309 filed June 27, 1967, special lenticulated films may be used having a lens array disposed on the side thereof opposite from that which carries the emulsion layers. Such a special lenticulated film would, of course, require a special emulsion capable of exposure from the inside of the film base and would, for all practical purposes, combine a lens array of the type shown in FIG. **1** with the film emulsion. The reverse printing systems shown in FIGS. **3, 3A, 4** and **4B** could be easily modified to accommodate such a lenticulated film.

As mentioned earlier, spherical lens overlays or arrays can be used in lieu of cylindrical lens overlays or arrays in a simplified camera construction of the type shown in FIG. **1** and in the conversion means shown in FIGS. **3, 3A, 4, 4B, 5, 7, 8** and **9.**

The systems for converting photographs having abnormal relief to those having normal relief as described above in connection with FIGS. **3, 4** and **5** may be considered, for practical purposes, modified contact printing systems which yield corrected photographs having substantially unity magnification. However, in some cases it may be desirable to include an enlargement or a reduction operation in conjunction with the corrective conversion of the abnormal relief characteristics. One suitable means for accomplishing the same is shown in FIG. **6** which illustrates, by way of example, means for effecting image enlargement in conjunction with correction of abnormal relief. It will be clear to those skilled in the art that the illustrated printing system could readily be modified to effect size reduction or for printing with unity magnification.

In the relief correcting system shown in FIG. **6,** each abnormal relief data strip $L_1 - R_1$ is individually printed in reverse order while each reverse-printed strip $L_2 - R_2$ is accumulated in the same order from left-to-right or from right-to-left, as in the original photograph. For illustrative convenience, the film reels **50** and **51** may be considered as moving clockwise and counterclockwise, respectively, so that the original abnormal negative or transparency **52** and the corrected or normal enlarged print **53** are both moved downward, as indicated by arrows **54.** The desired ratio of enlargement and of film displacement is precisely maintained by gears **55** and **56** having a respective tooth ratio equal to the enlargement desired. To simplify the diagram, the coupling of gears **55** and **56** to film reels **51** and **50** respectively, and the coupling of a film-advance knob **57** or other suitable means for film traverse to gear **56** and reel **50** are schematically shown by dotted lines. However, it will be clear that, for downward movement of film **52** and of film **53,** knob **57,** reels **50** and gear **56** must move in a clockwise direction while gear **55** and reels **51** must move in a counterclockwise direction.

Each relief data strip $L_1 - R_1$ on film **52** is printed in reverse order on film **53** as a strip $L_2 - R_2$ by a lens **58.** To prevent exposure of film **53** while index lines **3***b* are aligned on screen **65,** as hereinafter described, an opaque curtain shutter **72** is maintained in position to prevent light from entering aperture **71** in mask **62.** When alignment is accomplished, exposure of each data strip is then effected by opening the shutter **72** for the proper period by a suitable element **73** arranged to control the speed of traverse of a sequence of openings **75** in shutter **72** which may, if desired, be carried upon rollers **74,** as in the well-known cameras which utilize focal plane shutters. Film data strips $L_1 - R_1$ are illuminated by any suitable light source **60** via condensing lenses **61.** Exposure of film **53** to an extent greater than one film data strip $L_1 - R_1$ at any particular time is prevented by a suitable aperture **72** in mask **62.** To insure tightness of film **52** and film **53,** brakes **63** having friction linings **63***a* may be held in frictional contact with reels **50** and **51** by any suitable means. When desired in connection with lens **58** the assembly **64** containing film **53** may be simultaneously adjusted for focus through incorporation of a ground-glass focal monitoring screen **65** to allow visual supervision by an observer **66.** Focussing is accomplished by an adjusting knob **67,** reverse-turning pinions **68,** and gear racks **69** separately attached to assembly **64** and to screen **65.** Light for such monitoring is provided by a stationary flat 45° beam-splitter **70.**

As an aid to the precise alignment of films **53** and the lens array used for final viewing, film **52** may be provided with edge marks **3***b* which represent the positions of each edge or cusp **3***c* of lens elements **3***w* of the cylindrical lens array **3** used to expose the original abnormal photograph, as shown and already discussed in connection with FIG. **1.** FIG. **6A,** for example, shows one form of opaque location marks or lines **3***b* applied to the flat surface **3***a* of the lens overlay **3** used to obtain the original photograph. Such marks need by applied only near the edge of each cylindrical lens element **3***n* and under the cusp focused by each adjacent lens element. When the relief photograph is exposed, these marks will be transferred photographically to the film and will mark the positions of all points $L_1 - R_1$ across both edges of the film **52.** When these marks are transferred in the system of FIG. **6** to film **53** in conjunction with reversed points $L_2 - R_2$, the necessary accurate alignment of the lens array required for subsequent viewing of the corrected or normal photograph will be greatly simplified. During exposure of each corrected relief data strip $L_2 - R_2$ on film **53,** the operator is greatly aided in obtaining proper and accurate adjacent positioning of each such subsequent adjacent data strip by adjusting knob **57** until the marks **3***b* coincide with marks at L_{21} and R_{21} on screen **65** which correspond to the images of lines **3b** printed at points L_2 and R_2 on film **53.**

In order to effectively utilize the location marks **3***b*, which are essentially perpendicular projections of the cusp lines **3***c* as above described, an auxiliary collimating lens disposed closely adjacent to the multielement lens overlay **3** should be incorporated in the FIG. **1** type camera systems to insure that all points L_1 and R_1 are disposed perpendicularly beneath the cusps of the individual lens elements of the overlay **3** when the film **6**, or its equivalent, is exposed in such simplified camera constructions. While a suitable collimating lens is not shown in FIG. **1**, a suitable lens is disclosed in my copending application Ser. No. 649,308 filed June 27, 1967.

In contradistinction with the above and if the locating lines **3***b* are not located as perpendicular projections of the cusp lens **3***c*, but are located in position as projected on the undersurface **3***a*, as by the extension of lines passing between point P in the camera system illustrated in FIG. **1** and each cusp line **3***c* of the lens overlay **3**, then a collimating lens will not be required adjacent thereto as suggested above. When the locating lines **3***b* are so disposed in such revised positions, extreme points L_1 and R_1 of each relief data strip will fall accurately upon the locating lines **3***b* and such lines may then be used, as previously described, in connection with the FIG. **6** embodiment, or for other related purposes.

Referring now to FIG. **7**, there is disclosed a modified unit for reverse printing the abnormal image of a film **6** on a second film **14** that there produces a normal print in substantially the same manner as in the heretofore described corrective printing systems. More specifically, in the system shown in FIG. **7**, an image of the film **6** is projected by an auxiliary lens **28** upon a focal plane **23** which is substantially coincident with the lens elements **19***b* of a multielement overlay **19** incorporated in a lens system of the type heretofore disclosed and in conjunction with FIG. **4B** made up of elements **18** and **19** surmounting the film **14**. In the FIG. **7** embodiment, the overlaying lens element **20** of FIG. **4B** is dispensed with. As shown, the film **6** bearing the abnormal image is illuminated by a suitable light source **32** through condensing lenses **33**. In the described unit, and as schematically shown in FIGS. **4** and **7**, the tangent of the ray angle S/2 must be substantially the same as the ratio of the half width of the lens elements **18***n*, **19***b* and **19***n* to the thickness of the lens overlay elements **18** and **19**. When desired, the normal print on the second film **14** may be selectively enlarged or reduced by conventional adjustments of the position of the auxiliary lens **28** and the film **6** relative to the film **14** which preferably may be considered as fixedly positioned. Concurrently therewith, of course, the width of the individual lens elements **18***n*, **19***b* and **19***n* must be adjusted to match the width of each relief data strip in the image plane **23**.

In this embodiment lens **38***a* has the same purpose and relationship relative to the aperture of lens **28** as does lens **38** relative to diffuser **30**. Lens **38***a* also serves substantially the same purpose with respect to lens elements **18** and **19** as does lens **38** relative to elements **45**, **46** and **47**. The projected image of film **6** must, of course, be aligned so that the images of relief data points $L_1 - R_1$ on film **6** fail on the cusps formed by lens elements **19***b*. The image of film **6**, therefore, functions effectively as the actual film **6** in the system of FIG. **4**.

FIGS. **8** and **9** illustrate alternate constructions wherein the use of lens overlays, such as lens overlays **18** and **19**, adjacent the second film **14** is dispensed with and in lieu thereof a corrective overlay disposed adjacent the abnormal film is employed.

Referring now to these figures, FIG. **8** illustrates the projection of the abnormal image on film **6** into a corrected image on a focal plane **25** in space at unity magnification by an auxiliary corrective multi-element lens overlay **24** having a plurality of lens elements **24***n* on the surface thereof. As shown in FIG. **9**, this image plane **25** having its relief image data converted to normal form close to elements **24***n* is then projected in preselected size relationship by an auxiliary lens **28***a* directly upon film **14** as a normal relief image. In this disclosed system, the auxiliary corrective lens overlay elements **24***n* are adjusted to be coaxial with each discrete data strip R_1 and L_1 so that points L_1 and R_2 are located on lines perpendicular to the film **6**. In order to obtain the related condition in which all extreme R_1 and L_1 data points are imaged coincident with the imaging of the cusps of the lens array **24** on film **14**, a collimating lens **38** is included to allow the off-axis rays V and W to originate as parallel rays V_1 and W_1 upon emergence from the lens array **24**.

As will be apparent to those skilled in this art, the heretofore described printing systems of FIGS. **6**, **7** and **9** thus permit any desired reduction or enlargement of the image concurrently with the disposition of the corrected or normal image on the second film **14**.

As will now be apparent to those skilled in this art, the above-described method of converting abnormal three-dimensional representations thereof not only permits the salvaging of abnormal three-dimensional film or transparencies but also makes utilization of the heretofore described simplified relief photographic apparatus a practical and utilizable reality.

As will also be apparent, the described printing conversion method is not only simple and inexpensive but is capable of providing the high degree of technical quality required for industrial three-dimensional photographs and for three-dimensional lithographed illustrations printed from three-dimensional transparencies.

Having thus described my invention, I claim:

1. Apparatus for reproducing relief photographs constituted by a sheet of film having a plurality of elongated relief data strips each containing a continuous sequence of relief image data in reverse orientation thereon comprising

illumination means disposed on one side of said photograph,

at least one multi-element lens overlay disposed in predetermined spaced relationship with the other side of said photograph with the individual lens elements thereof being disposed in respective longitudinal alignment with said relief data strips thereon said multielement lens overlay including optical barrier means disposed intermediate each lens element thereof, and

a photosensitive film disposed in static adjacent relation to said overlay and exposable to said inverted images of each such sequence of relief image data on each said data strip produced by the lens elements of said lens overlay to reproduce said relief image data in natural orientation.

2. Apparatus for reproducing relief photographs constituted by a sheet of film having a plurality of elon-

gated relief data strips each containing a continuous sequence of relief image data in reverse orientation thereon comprising

illumination means disposed on one side of said photograph,

at least one multi-element lens overlay disposed in predetermined spaced relationship with the other side of said abnormal photograph with the individual lens elements thereof being disposed in respective longitudinal alignment with said relief data strips thereon,

a photosensitive film disposed in static adjacent relation to said overlay and exposable to said inverted image of each such sequence of relief image data on each said data strip produced by the lens elements of said lens overlay to reproduce said relief image data in normal orientation, and

a second multielement lens overlay disposed intermediate said first mentioned lens overlay and said photograph.

3. Apparatus for reproducing relief photograph constituted by a sheet of film having a plurality of elongate relief data strips each containing a continuous sequence of relief image data in reverse orientation thereon comprising

illumination means disposed on one side of said photograph including

an auxiliary collimating lens disposed closely adjacent to said film and

an extended area light source disposed remote from said collimating lens at its focal distance and

at least one multi-element lens overlay disposed in predetermined spaced relationship with the other side of said photograph with the individual lens elements thereof being disposed in respective longitudinal alignment with said relief data strips thereon and

a photosensitive film disposed in static predetermined spaced relation to said overlay and exposable to said inverted images of each such sequence of relief image data on each said data strip produced by the lens elements of said lens overlay to reproduce said relief image data in normal orientation.

4. Apparatus as set forth in claim **3**

including a third multielement lens array disposed intermediate said auxiliary collimating lens and said abnormal film.

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