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THE ANAGLYPH AND A STUDY ON ITS VISUAL GEOMETRIC MODEL DEFORMATIONS

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ABSTRACT

Anaglyphic illustrations are more than a Century old. It has always been an interesting topic for scientists. Modern developments in Photogrammetric data analysis can be conveniently used for understanding the phenomena and geometry of human vision. The anaglyph should really be considered as a bridge between the client and the Photogrammetrist, as the client by viewing the anaglyph will easily get motivated to properly appreciate the capabilities of Photogrammetry.

The process of presenting undistorted equivalent Digital terain model like vision through anaglyphs is a challenge. The concept of 'Geodetic Intersections' is currently in usage by Physists and Optometrists in their efforts to understand human vision. The brain, by virtue of the psychological experiences, will present to the eye a likable three dimensional model while viewing anaglyphs, and such a model is nearer to the concept of an undistorted equivalent Digital terrain model than to the concept of Geodetic Intersections. The study indicates that the eye lenses have predominent distortions, which probably help in depth exaggeration.

A few potential areas of applications are briefly indicated. The illustrations given are of quick appeal and are expected to be appreciated by many International Scientists and Citizens.

A few conclusions and recommendations are listed.

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INTRODUCTION:

Rollman (1853) and D'Almeida (1858) are the pioneers in the development of the anaglyphic method of stereoscopic viewing. The Multiplex is a notable example of a stereoscopic plotting instrument which is based on the principle of making three Dimensional measurements on a 'Rectified Anaglyphic Stereo-Model'. However, the Anaglyphic illustration often given in Photogrammetric literature has been directly compiled from unrectified photographs. The practical applications of the anaglyphs have not been developed to the optimum extent. In practice, the anaglyph can easily be used to effectively bridge the gap between the practising photogrammetrist and his client. Once the client views the anaglyph of the object to be mapped, there will remain no doubt in his mind that reliable metric measurements and mapping of the object can be conveniently made from the component Photographs. Also, in certain applications in Architecture, it is often desired to produce Anaglyphs which are visually undistorted. The logical first step in this direction is

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to properly understand the geometry of the anaglyphic model. Here, some attempt will be made to understand and hence underline the visual geometric distortions of the stereoscopic model.

The anaglyphs of aerial scenes are more familiar and common. However, anaglyphs of terrestrial or close-range scenes are also practicable and useful. The component images of the anaglyph could be either drawn, printed or projected in complementary colours. The drawn anaglyphs may be rendered free from the lens distortions and other errors peculiar to the Photographs. Also, the drawn anaglyphs are well suited for simulation studies. The colour blindness of the observer does not effect the spacial perception. The complementary colours red and green is said to be better than blue and yellow or blue and red.

The anaglyph is a picture in which the two component images are superimposed, say one in green and the other in red. The tinted eye glasses are used to seperate the images for the left and right eye respectively. Each eye therefore sees only the intended black and white picture, resulting in the illusion of depth. The superimposition could be so arranged as to result in 'Homonymous Diplopia' with reference to the plane of the paper. Then the visible model will be placed behind the plane of the paper. If the component images are so super-imposed as to result in 'Heteronomous Diplopia', then the visible stereoscopic model will be seen in fromt of the plane of paper.

If the tonal values of one of the Photographs is reversed by using the negetive in place of the positive, then there is tonal reversal between the impressions produced on the left and right eye respectively. This, if the conflict is resolved by the mechanism of perception, will result in a stereoscopic sparkle.

Also, conceptually a desired systematic distortion of the visual stereomodel could be achieved by a suitable distortion of the component images. Such illustrations may be used in geometric studies of the anaglyph, and in certain special applications.

2. CONDITIONS OF BINOCULAR VISION:

Only when conditions similar to those that exist at the time of natural binocular vision are simulated, it will be possible to obtain the illusion of depth. When the simulated conditions are not identically the same as at the time of natural binocular vision, there is a perceptible visual deformation of the illusive plastic model. But, when the simulated conditions are not conducive to obtaining of three dimensional vision at all, then the binocular vision fails to materialize. The conditions that induce stereovision may be listed as follows:

1. Stereo images should be presented practically simultaneously to each eye. The two images, at least theoretically, should not be congruent but should exhibit relative parallaxes. The two monocular images should fall on the common binocular visual field of the two retinae. Also, the two monocular images should include the fovea for each eye.

2. The lines from the left and right eye to each of the pairs of corresponding points should at least approximately intersect in space. In otherwords, the epipolar condition should be satisfied.

3. The physiological process of conveying the impressions of the right and left images to the associated regions of the cortex should take place.

4. The eye should be able to successively direct the gaze at a number of points, particularly close to the fovea, so that the spatial impression is 'built up'.

5. The brain should function in an imaginary and constructive way so as to bring into being the illusion of depth.

6. Another condition, peculiar to anaglyphs, is that the 'total seperation' or the maximum 'absolute parallax' for any pair of corresponding points should be less than that of the interocular distance of 65 to 70 mm.

The element of relative parallax or the relative convergence is only one of the factors which contributes to the perception of depth. In binocular vision the axes of the eyes do not remain fixed in one position, but a number of points within the visual field are fixed in succession and the resulting 'feelings' are compounded together in someway. This is therefore another element which contributes to perception of depth.

3. THE CONCEPT OF GEODETIC INTERSECTIONS:

The human eye essentially consists of a convex lens, known as the crystalline lens, in front and a sensitive membrane behind known as Retina. In fact, the eye very favourably compares with a camera consisting of a shutter and a lens system. The retina contains hundreds of cones and rods whose main function is to receive light pulses and to transform the same to electrical currents. These electrical currents are translated by the brain into vision.

Figure 1 shows the 'Gullstrands Schematic Eye' which may be taken as a representation of normal human eye. The dimensions shown are all in millimeters. The refractive index of water is 1.34. The refractive index for the acqueous humour of the eye is also 1.34. But the refractive index for the Cornea and the Crystalline lens is about 1.40. The overall power of the standard eye is 58.64 Diopters. For theoretical studies using the above data, it is possible to calculate relative object and image positions by use of rigorous ray tracing formulae. However, an immediate word of caution is in order. Sometimes, the human vision, which is usualy relied upon to convey the truth, can become quite unreliable. The whole group of 'Optical illusions', given in many a book, illustrate the unreliable nature of impressions produced by the eye.

The Photogrammetrist is too familiar with the Geometrical concepts of collinearity, coplanarity, relative orientation and absolute oreintations. In viewing the stereo-images under the stereoscope or while viewing the anaglyph with the filter spectacles, apparently much the same sort of phenomena takes place. One important geometric concept used to explain this is termed "The Concept of Geodetic Intersections". Here the individual eye in its turn takes on the role of an observing theodolite used in measuring horizontal and vertical angles and the interocular base provides the geodetic base. Thus, a mental triangulation surveying accompanied by a graphical or mental plotting takes place resulting in the three dimensional perception (1). In otherwords, this concept relies only on the relative parallax and relative convergence in building up the visual model. As this concept is geometric in nature, its validity can be easily checked by a suitable simulation study.

4. VISUAL GEOMETRIC MODEL DEFORMATION STUDY:

For purposes of the mathematical treatment, certain assumptions-none of which are true in practice - are often made.

1. The composite eye lens is distortion free.
2. Geometrically, the eye system acts as a camera system.

3. The Ratinae are truely spherical

4. The nodal points and centres of rotation coincide.

5. There is true mathematical symmetry in the correspondence of the retinal points or areas.

6. Rotation of the eye globes around their visual axes is strictly geometric.

7. The axes of the eye fix a single point in space and so for each model perceived by a given individual, there is a single 'Horopter Surface'.

8. Imperfect position of the photographs or the anaglyphs and the imperfect positioning of the eyes are effectively compensated by the brain after it receives messages from the occular muscles and neck muscles etc.

9. The retinal meridians are truely horizontal and vertical respectively.

10. The physiological and mental processes tend to convert the perspectively produced visual model to its equivalent 'Undistorted Digital Terrain Model', centered at the 'Cyclopan Eye'.

TABLE 1: THREE DIMENSIONAL COORDINATES, (IN METERS), OF OBJECT SPACE POINTS AND EXPOSURE STATIONS.

Point No.	X	Y	Z	Point No.	X	Y	Z	Point No.	X	Y	Z	Point No.	X	Y	Z	Point No.	X	Y	Z
A1	0	10	20	B2	9	9	22	C3	8	2	24	D4	3	3	26	FO	5	5	30
A2	10	10	20	B3	9	1	22	C4	2	2	24	E1	4	6	28	LS	4.9	5	0
A3	10	0	20	B4	1	1	22	D1	3	7	26	E2	6	6	28	RS	5.1	5	0
A4	0	0	20	C1	2	8	24	D2	7	7	26	E3	6	4	28				
B1	1	9	22	C2	8	8	24	D3	7	3	26	E4	4	4	28				

LS: Left Camera station ; RS: Right Camera station.

Note: FO: Middle Point of model

TABLE 2: PHOTO COORDINATES (IN MILLIMETERS); LEFT (x_1, y_1) AND RIGHT $(x_2,$

Camera axes parallel. Normal case: camera constant = 3

$$x_1 = c\,\frac{X - X_{LS}}{Z - Z_{LS}} \;;\quad x_2 = c\,\frac{X - X_{RS}}{Z - Z_{RS}} \;;\quad y_1 = c\,\frac{Y - Y_{LS}}{Z - Z_{LS}} ;\; y_2 = c\,\frac{Y - Y_{RS}}{Z - Z_{RS}}$$

Point No.	x_1	$y_1 = y_2$	x_2	Point No.	x_1	$y_1 = y_2$	x_2
A1	-73.500	+ 75.000	-76.500	D1	-21.923	+23.077	-24.231
A2	+76.500	+ 75.000	+73.500	D2	+24.231	+23.077	+21.923
A3	+76.500	- 75.000	+73.500	D3	+24.231	-23.077	+21.923
A4	-73.500	- 75.000	-76.500	D4	-21.923	-23.077	-24.231
B1	-53.182	+ 54.545	-55.909	E1	- 9.643	+10.714	-11.786
B2	+55.909	+ 54.545	+53.182	E2	+11.786	+10.714	+ 9.643
B3	+55.909	- 54.545	+53.182	E3	+11.786	-10.714	+ 9.643
B4	-53.182	- 54.545	-55.909	E4	- 9.643	-10.714	-11.786
C1	-36.250	+ 37.500	-38.750	FO	+ 1.000	0.000	- 1.000
C2	+38.750	+ 37.500	+36.250				
C3	+38.750	- 37.500	+36.250				
C4	-36.250	-37.500	-38.750				

Now, an attempt will be made to study the geodetic intersection concept. Figure 2 shows the relative location of selected points, the dimensions being given in meters. Table 1 gives the three dimensional coordinates in meters of the selected object space points and the exposure stations. Table 2 gives the photo coordinates in millimeters in left and right photographs. Table 3 gives the model coordinates obtained under the assumption of Geodetic Intersections. Figure 3 shows the anaglyph obtained by simulation. For this purpose, it is assumed that the left and right photographs are so superimposed as to make the point FO in each, coincide. For the calculation of the photo coordinates of points, the geodetic intersection concept is used. The anaglyph with the heternomous diplopia with reference to the plane of the paper is drawn.

The following steps are used in the calculation of the three dimensional coordinates of model points. Let,

$\angle L$ = Angle formed at the left eye

$\angle R$ = Angle formed at the right eye

r = Angle of convergence formed at the model point.

b = eye base (70 mm)

x,y,z = Three dimensional coordinates of the model point

H = Viewing Distance (300 mm)

Then,

$$\angle L = 90 - \mathrm{Tan}^{-1} \left\{ \frac{x(\text{left photo})^{-1} - 35}{300} \right\}$$

$$\angle R = 90 + \mathrm{Tan}^{-1} \left\{ \frac{x(\text{right photo})^{+1} - 35}{300} \right\}$$

$$\angle r = 180 - \angle L - \angle R$$

$$z = 300 - \frac{b.\text{Sin}\angle L \, . \, \text{Sin}\angle R}{\text{Sin}\angle r}$$

$$x = x_{(\text{left photo})} - 1 - \frac{b.\text{Sin}\angle L \, . \, \text{Sin}\angle R}{\text{Sin}\angle r \, . \, \text{Tan}\angle L}$$

$$y = \frac{y_{(\text{left photo})} \cdot \sqrt{z^2 + (x + 35)^2}}{\sqrt{H^2 + (x_{(\text{left photo})} - 1 + 35)^2}}$$

TABLE 3: MODEL COORDINATES OBTAINED UNDER THE ASSUMPTION OF GEODETIC INTERSECTIONS (Dimensions in Millimeters)

Point No.	x	y	z	Point No.	x	y	z
A1	-73.944	+73.944	+295.775	D1	-22.976	+22.976	+298.686
A2	+73.944	+73.944	+295.775	D2	+22.976	+22.976	+298.686
A3	+73.944	-73.944	+295.775	D3	+22.976	-22.926	+298.686
A4	-73.944	-73.944	+295.775	D4	-22.976	-22.976	+298.686
B1	-53.985	+53.984	+296.916	E1	-10.693	+10.692	+298.388
B2	+53.985	+53.984	+296.916	E2	+10.693	+10.692	+299.388
B3	+53.985	-53.984	+296.916	E3	+10.693	-10.692	+299.388
B4	-53.985	-53.984	+296.916	E4	-10.693	-10.692	+299.388
C1	-37.234	+37.234	+297.872	F0	0.000	0.000	300.000
C2	+37.234	+37.234	+297.872				
C3	+37.234	-37.234	+297.872				
C4	-37.234	-37.234	+297.872				

Tables 4 and 5 give an idea of the variations in scale in the x y plane and in the z direction.

TABLE 4: Scale Variation in x y plane

Plane	Line	Object Distance (m)	Model Distance (mm)	Scale
A	A1-A4	10.0	147.888	1 in 67.6
B	B1-B4	8.0	107.968	1 in 74.1
C	C1-C4	6.0	74.468	1 in 80.6
D	D1-D4	4.0	45.952	1 in 87.0
E	E1-E4	2.0	21,384	1 in 93.5

TABLE 5: Scale variation in z direction

From Plane	To Plane	Object Depth (m)	Model Depth (mm)	Depth Scale
A	B	2.0	1.141	1 in 1753
B	C	2.0	0.956	1 in 2092
C	D	2.0	0.814	1 in 2457
D	E	2.0	0.702	1 in 2849
E	F	2.0	0.612	1 in 3268

It is now desired to calculate the coordinates of an equivalent undistorted digital terrain model, using the planimetric scale of plane C and the corresponding distances of points in that plane. These values are tabulated in Table 6. It is logical to compare the three dimensional coordinates obtained by the geodetic intersection with those obtained for the equivalent

TABLE 6: IDEAL MODEL COORDINATES

Point	x (mm)	y (mm)	z (mm)
A1	-62.057	+62.057	248.227
A2	+62.057	+62.057	248.227
A3	+62.057	-62.057	248.227
A4	-62.057	-62.057	248.227
B1	-49.645	+49.645	273.050
B2	+49.645	+49.645	273.050
B3	+49.645	-49.645	273.050
B4	-49.645	-49.645	273.050
C1	-37.234	+37.234	297.872
C2	+37.234	+37.234	297.872
C3	+37.234	-37.234	297.872
C4	-37.234	-37.234	297.872
D1	-24.823	+24.823	322.695
D2	+24.823	+24.823	322.695
D3	+24.823	-24.823	322.695
D4	-24.823	-24.823	322.695
E1	-12.411	+12.411	347.518
E2	+12.411	+12.411	347.518
E3	+12.411	-12.411	347.518
E4	-12.411	-12.411	347.518

Undistorted digital terrain model. These differences are tabulated in Table 7.

TABLE 7: DIFFERENCES IN THE THREE DIMENSIONAL COORDINATES

Id: Ideal equivalent undistorted Digital terrain model

Geo: Coordinates obtained by assumption of Geodetic intersections

Point No.	$x_{id} - x_{geo}$	$y_{id} - y_{geo}$	$z_{id} - z_{geo}$
A1	+11.887	-11.887	-47.548
A2	-11.887	-11.887	-47.548
A3	-11.887	+11.887	-47.548
A4	+11.887	+11.887	-47.548
B1	+ 4.340	- 4.340	-23.866
B2	- 4.340	- 4.340	-23.866
B3	- 4.340	+ 4.340	-23.866
B4	+ 4.340	+ 4.340	-23.866
C1	0	0	0
C2	0	0	0
C3	0	0	0
C4	0	0	0
D1	- 1.847	+ 1.847	+24.009
D2	+ 1.847	+ 1.847	+24.009
D3	+ 1.847	- 1.847	+24.009
D4	- 1.847	- 1.847	+24.009
E1	- 1.718	+ 1.718	+48.130
E2	+ 1.718	+ 1.718	+48.130
E3	+ 1.718	- 1.718	+48.130
E4	- 1.718	- 1.718	+48.130

The Planimetric model deformations produced may be studied by comparison. These results are tabulated in Table 8.

TABLE 8: PLANIMETRIC MODEL DEFORMATIONS: (r ; radial distance)

Point	r_{geo} (mm)	r_{id} (mm)	$\Delta r = r_{id} - r_{geo}$ (mm)	$\frac{\Delta r}{r_{geo}}$
A1	104.58	87.76	-16.811	0.1607
A2	104.58	87.76	-16.811	0.1607
A3	104.58	87.76	-16.81	0.1607
A4	104.58	87.76	-16.811	0.1607
B1	76.35	70.21	- 6.138	0.0804
B2	76.35	70.21	- 6.138	0.0804
B3	76.35	70.21	- 6.138	0.0804
B4	76.35	70.21	- 6.138	0.0804
C1	52.66	52.66	0	0
C2	52.66	52.66	0	0
C3	52.66	52.66	0	0
C4	52.66	52.66	0	0
D1	32.493	35.110	+ 2.612	0.0804
D2	32.493	35.110	+ 2.612	0.0804
D3	32.493	35.110	+ 2.612	0.0804
D4	32.493	35.110	+ 2.612	0.0804
E1	15.120	17.550	+ 2.430	0.1607
E2	15.120	17.550	+ 2.430	0.1607
E3	15.120	17.550	+ 2.430	0.1607
E4	15.120	17.550	+ 2.430	0.1607

Vertical exaggeration in stereo viewing occurs because the horizontal and vertical scales are unequal. An expression given in (7) is as follows:

$$V = \left(\frac{B}{H'}\right)\left(\frac{h}{be}\right); \text{ where}$$

B = Air Base

H' = Flying height

h = model distance

be = eye base

If corresponding values for the geodetic intersection method are substituted, we get

$$V = \frac{0.2}{24} \times \frac{300}{70} = \frac{1}{28}$$

If the horizontal scale and vertical scale at plane C are compared,

$$V = \frac{80.6}{2457} = \frac{1}{31}$$

However, when the anaglyph is viewed, it is easily seen that these exggeration factors are in gross error.

Another question in stereo vision, is the relation between the space impression given by the anaglyph and that obtained by direct observation from the camera station. The depth perception improves by a factor nv, where n is the ratio between photography base and the eye base and v is the magnification factor of the lens stereoscope.

In the present anaglyphic case,

n = (0.2 x 1000) /70 = 2.9. v being unity, this n is the factor by which our ability to judge depth improves.

A FEW ILLUSTRATIONS OF ANAGLYPHS

In figure 4, an aerial anaglyph familiar to the photogrammetrist is given, the aerial photographs were taken from a Hasselblad camera with a focal length of 80 mm and the original scale of photograph was about 1:22,000. The photographs were enlarged 4 x and then used for making the anaglyph. It is interesting to note that anaglyphs made from 2.7 x enlargement of the same original photographs was far from satisfactory and the depth of even tall was hardly discernible.

In figure 5, a terrestrial anaglyph of the local state assembly building is presented. The photographs were taken from an amateur 35 mm camera (Ricoh), with 40 mm focal length and then enlarged 6 x.

In figure 6, another terrestrial anaglyph of one of the famous Shila-Balika statue (Dancing beautiful maiden carved in stone) of Belur, Hassan District, Karnataka State, India is shown. Again the same 35 mm camera was used with an object distance of 1 m. In that famous temple there are at present 38 rare stone carvings of a similar kind.

SOME AREAS OF APPLICATION:

Adult education: Use of audio-visual aids in education in general and adult education in particular is well known. A picture is worth a hundred words. If so, surely an anaglyph is worth a thousand words. Illustrated anaglyphs will provide a strong motivation for learning in adult education programmes.

Rural Development: The language of the anaglyph is universal. Anaglyphs of model villages and towns can be made and distributed among the uneducated farmers in developing countries. Using this as a base, it is easy to formulate and implement many a rural development scheme in such countries.

Archaeology: Use of Photogrammetry in preserving and reconstructing of archaeological specimens and structures is well known in developed countries. In developing countries, the anaglyph will provide a strong motivation for the archaeologist to get all worthwhile archaeological treasures mapped and documented.

Tourism Development: Tourist spots of national and international importance and interest can be documented in the form of anaglyphs and used for publicity and tourism development. It permits a selective choice when tour itenerary is to be drawn up.

Architecture: The architectural monument is clearly and vividly brought home to the beholder through the anaglyph. Hence, efforts in producing an undeformed equivalent, scaled stereomodel in the form of anaglyphs will be highly appreciated.

Police investigations: Anaglyphs of accident prone spots and also actual accidents help in public education. Anaglyphs made from photographs taken from different view points of an accident scene can be used in accident studies and in investigations.

Remote Sensing: One of the main reasons for the use of black and white single photographs as the basis for interpretations is that suitable popular three dimensional visual techniques and consequent interpretation methods are lacking. The anaglyph technique can be fully developed and used to fill this gap.

Highway Engineering: The preparation of Photo-montage for publicity purposes in Highway development is well known. From such photographs, anaglyphs can be made and used for the same purpose, probably with a greater degree of success.

Town planning: This is a field of study and development, wherein experts in a number of disciplines and specialities should work together. In this, the anaglyphs can be conveniently used for information exchange.

Study of the phenomena of vision: The field of visual optics is not based on the same pedastal as geometric optics using lenses, mirrors and prisms. In visual optics, personal factors and the interpretations provided by the human brain come into prominent play. The anaglyphs with visual distortions intensionally built into them can contribute to a better understanding of the phenomena of human vision.

CONCLUSION:

1. A visual study of the illustration of the drawn anaglyph indicates to the fact that the visual model is rather very much closer to the undistorted equivalent digital terrain model than the model obtained by geodetic intersections.

2. It is clear that the eye lens system has considerable distortions and its behaviour is far from that of a perfect lens. So, it is quite likely that the radial distortions produced increase the differential parallaxes resulting in modification of visual depth values.

3. The variation of scale in the direction of depth is not uniform. Hence, human vision is not the case of an orthogonal affine

deformation involving only change of scale in the direction of depth. This also follows from a careful study of the results of simulation study presented here.

4. The question of producing absolutely distortion free anaglyph is a tricky one and should be accepted as a challange by the modern photogrammetrist.

RECOMMENDATIONS:

1. The modern analytical photogrammetric techniques have converted the non-metric camera systems into more useful metric systems by providing effective analytical means and techniques for analyzing imagery obtained from such cameras. These techniques should also be applied to a thorough and scientific study of the phenomena of vision.

2. The analytical plotters or preferably other simpler and less costly instrumentation should be improvised and improved for the simulation of distorted and undistorted anaglyphs.

3. Various applications involving use of anaglyphs as a medium of information exchange or transfer should be developed and used in such fields as Adult education, Rural development, Architecture, Tourism development etc.

4. Use of three dimensional vision in photo-interpretation and Remote sensing has not gained momentum mainly because of the nonavailability of easy and economical methods of providing such three dimensional perception. The large scale use of anaglyphs and similar techniques may be considered as useful in bridging this gap.

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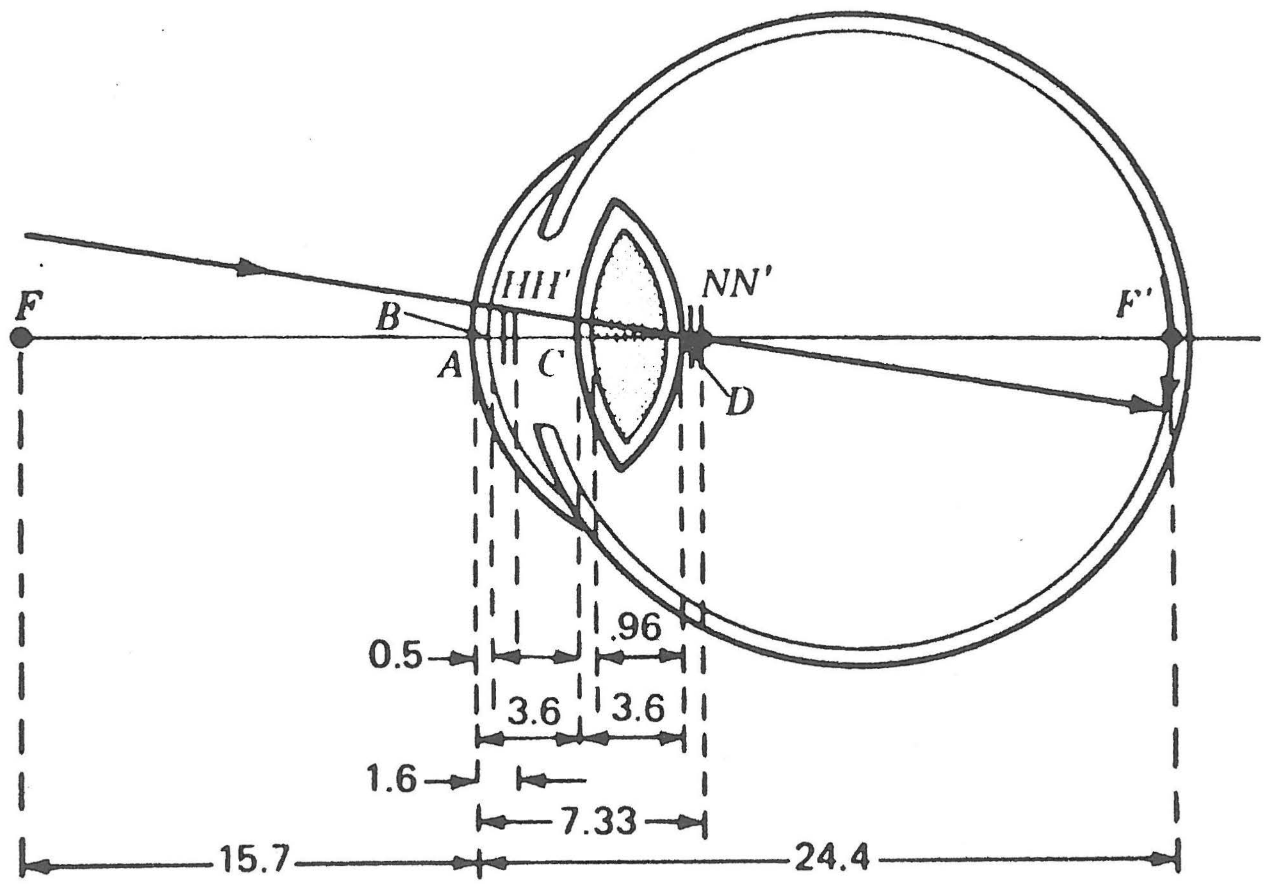

Figure 1: Gulstrands Schematic Eye (All dimensions in Millimeters)

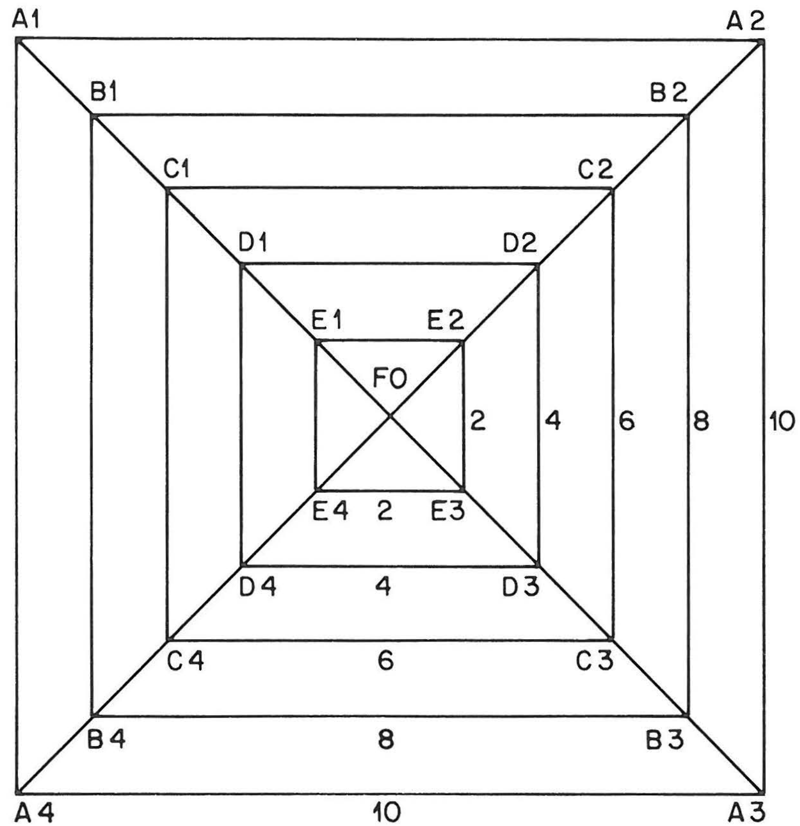

Figure 2: Relative Locations of Selected Model Points.
(All dimensions in meters).

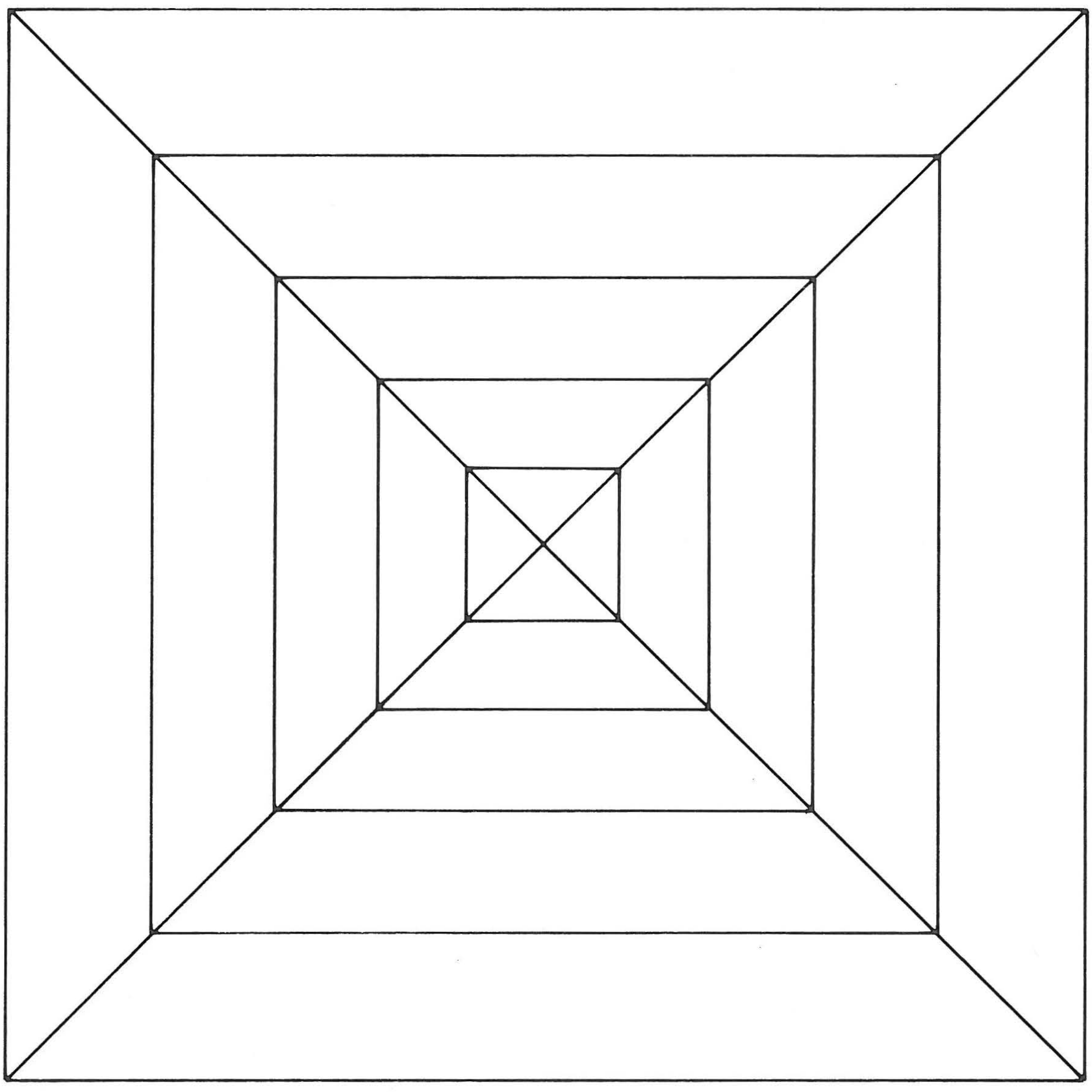

Figure 3(a): Simulated Left Photograph

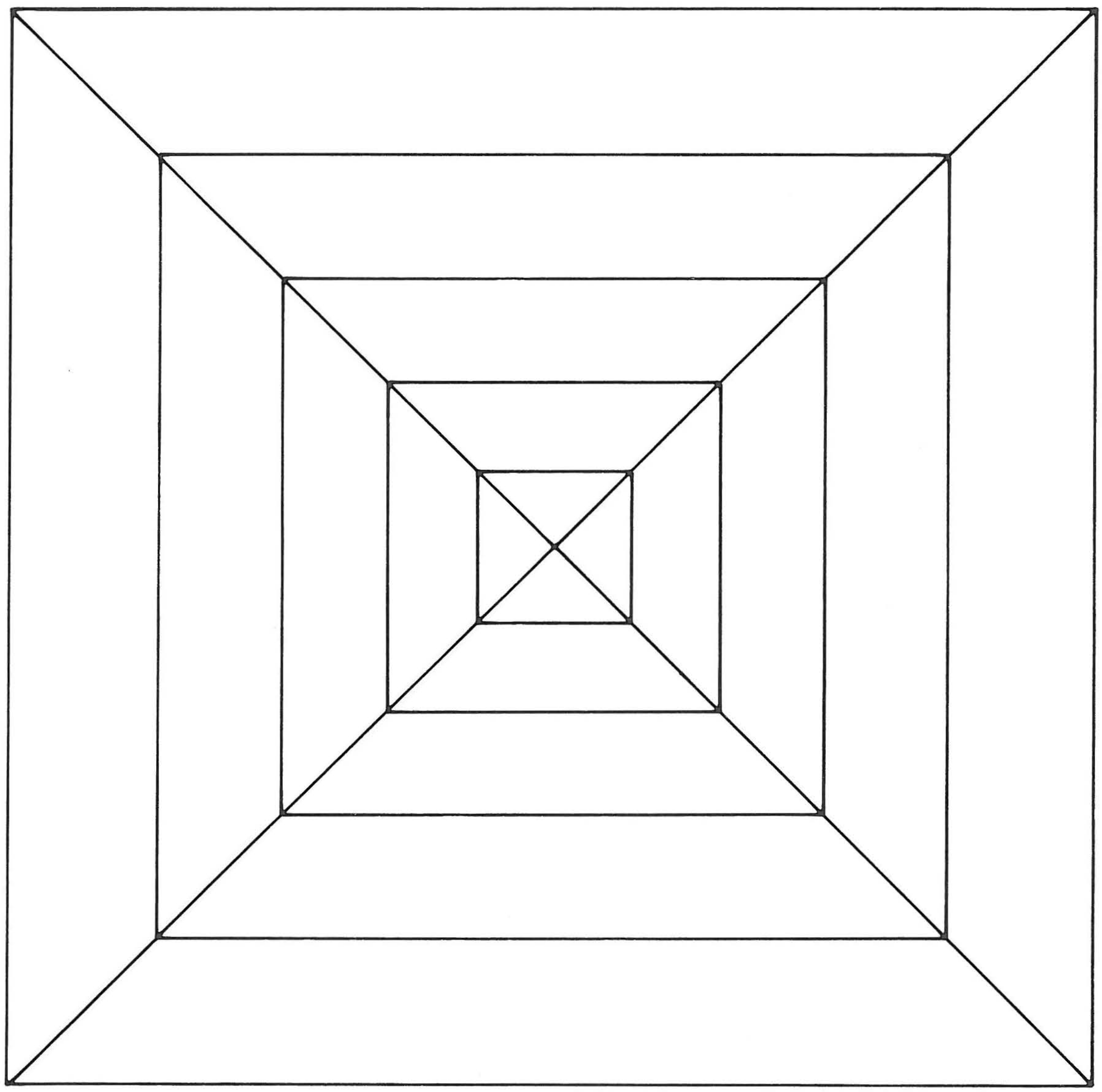

Figure 3(b): Simulated Right Photograph

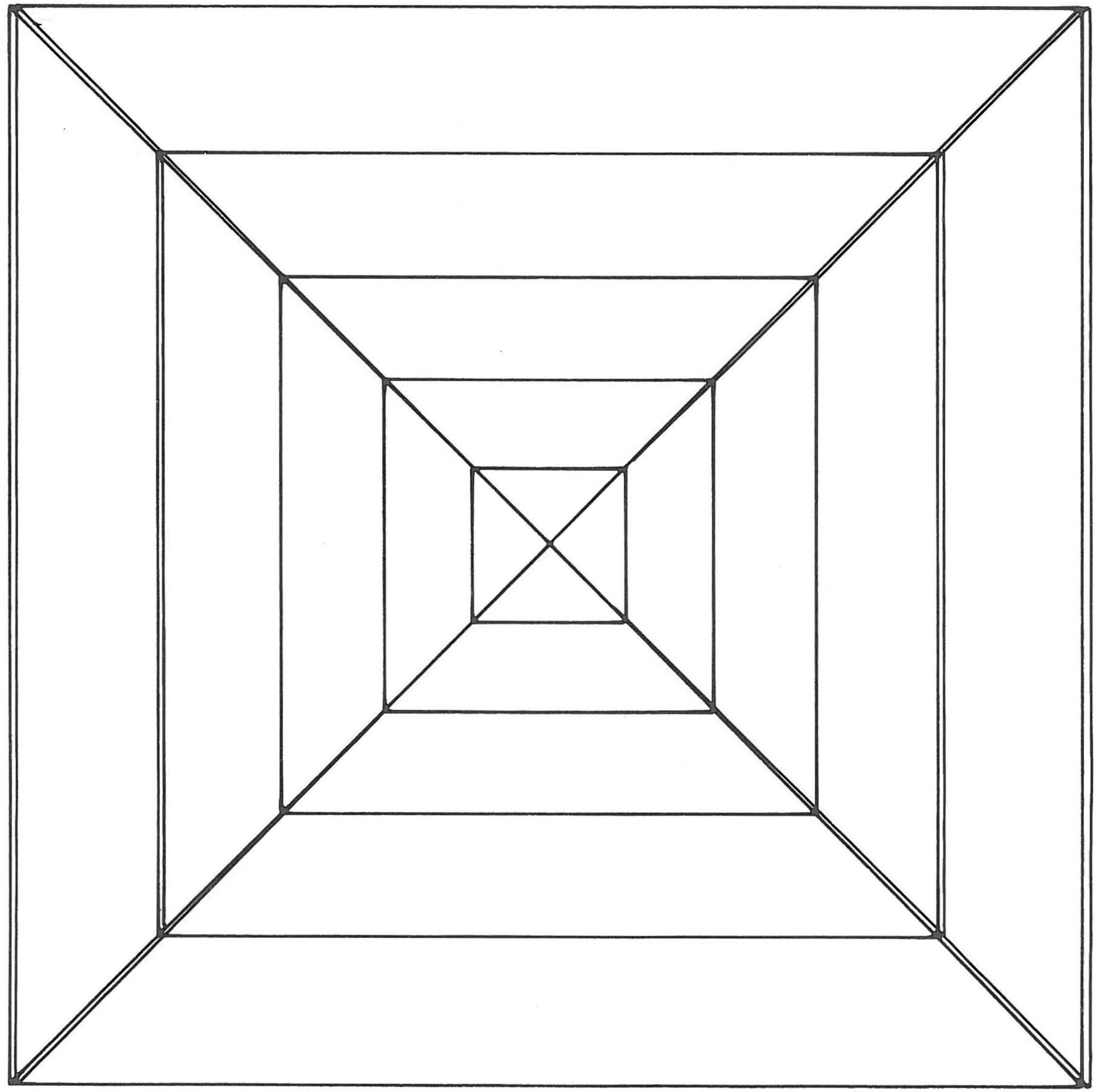

Figure 3(c): Simulated Anaglyph: Green outline is Left Photo and Red outline is Right Photo.