A REVIEW OF FACTS AND TERMS CONCERNING THE STEREOSCOPIC EFFECT

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REVIEW

Many articles have been published in "PHOTOGRAMMETRIC ENGINEERING" concerning the subject of relief exaggeration. A review of these articles indicated significant differences in the presentation of the subject matter by the various authors. Recently, photo interpreters have demonstrated a genuine interest in the subject of relief exaggeration for the solution of related problems. In reviewing the available literature, some photo interpreters and photogrammetrists reported that they were confused owing to the inconsistencies existing in the various papers. The Publications Committee requested Dr. Aschenbrenner to review the literature and present a paper so as to reconcile the differences and define the terms.

Dr. Aschenbrenner, being well versed in the fields of photo interpretation and photogrammetry, has clarified many of the differences on this rather controversial subject in this very interesting and informative paper.

GOMER T. MCNEIL
Chairman, Publications Committee

IN TWO previous papers[1,2*] the author has treated some aspects of the stereoscopic effect, i.e. a perception of tridimensional form induced by a pair of photographs and similar, though not quite equal, to space perception in natural binocular vision.

Mr. Beltman's article[3] in this issue, as well as a number of earlier publications on the subject (see Bibliography) seem to indicate a wide range of disagreement among experts as to the evaluation of the stereoscopic effect and the right interpretation of stereoscopic relief. Upon closer examination, however, it will be found that this is mostly a disagreement on terms rather than on facts and theories. This is quite understandable: stereoscopic pictures, especially stereoscopic air photographs, are being used for many different purposes by people with widely differing experience and interest. Each one is naturally inclined to emphasize his own point of view, and to pay less attention to parts of the problem with which he is not immediately concerned.

In the following, an attempt is made to describe the essential features of the stereoscopic effect in a language which might be acceptable to all photogrammetrists, and to reconcile presentations which seem to be conflicting.

A stereo pair gives an impression of space similar to the one we perceive in natural binocular vision. The stereo effect differs from natural vision in two essentially different ways:

1. The object shown by a stereo pair is taken out of its natural surrounding and context. Looking at a stereo pair always involves either the use of some instrument (stereoscope, polaroid viewers), or the use of the eyes in an unnatural way (fixed position of head, unnatural convergence and accommodation), in order to let each eye see only the coordinated picture and not the other one. The resulting visual irritation aand muscle strain, however, can be overcome by experience within reasonable limits and shall not be considered further.
2. A stereo pair, properly oriented, gives always an impression of space, of an arrangement of things in three dimensions. But this arrangement in three dimensions is not necessarily—and certainly not in stereoscopic air photography—the same as perceived in natural vision. What is it, then? The answer to this question is the subject of this paper.

* Numbers[1,2] etc. refer to bibliography at the end of this paper.

We shall restrict ourselves to the "normal case of stereoscopy," or stereopairs exposed in "horizontal coplane."† In conventional vertical air photography with sixty per cent overlap, this case is closely approximated. We shall further restrict the discussion to objects which are small compared with their distance from the camera or the eyes.

When we attempt to describe the stereoscopic effect we are faced with the difficulty that "seeing" an arrangement of objects in three dimensions means two different things, namely:

1. receiving light rays from different directions, and
2. interpreting these directions in terms of distance to the object, and of length, width and height of the object.

This second phase of seeing is a function of the brain and based upon accumulated experience and knowledge; it is, therefore, a very personal matter and does not lend itself readily to a rigorous treatment. The first phase of seeing, however, is purely geometrical and can, in the case of the stereoscopic effect, be described entirely by stating, that light rays coming from the image points of a stereo pair are hitting the eyes in directions *as if* they came from a real tridimensional object. Let us call this "as if"-object the visual stereoscopic model. It may be identical with the actual object or it may differ from it in scale, distance, and shape.

This visual stereoscopic model is not to be confused with another type of stereoscopic model: the stereoscopic model which is produced by stereoscopic plotting instruments, and scanned with a floating mark in the plotting process. Let us call this kind of stereoscopic model the instrument model.

If a stereo pair is properly oriented in a stereoscopic plotter such as the Multiplex, the instrument model is always a reduced, geometrically similar reproduction of the actual object. The visual model, however, which is perceived by the operator of the plotting instrument, is not necessarily geometrically similar to the object. This will be easily recognized when we observe the stereoscopic model on the tracing table of a Multiplex: it seems to change its shape when we move our head with respect to the tracing table. However, these distortions or deformations of the visual model do not affect the plotting process, since if the floating mark is in contact with a point in the visual model, it is also in contact with the same point in the instrument model, no matter how the surrounding of this point may appear to the operator.

But the moment we attempt to draw further metric information from the visual model, such as estimating the steepness of a slope without moving the floating mark, we are in trouble. Our visual model is distorted, in a different way for each position of our head with respect to the stereo pair projected on the tracing table. Thus the steepness as immediately perceived is certainly not the true one. The true slope angle could only be found by correcting our visual impression for the deformation of the visual model, and that would involve a geometrical analysis of the whole situation.

These ever changing deformations of the visual model go usually unnoticed by the Multiplex operator because he is not seeking metric information from the visual model at all; he only uses it for recognizing what he is plotting, and for establishing or maintaining precise coincidence of floating mark and terrain. It is at this point that he becomes interested in another quality of the visual model. He will ask: How accurately can I establish coincidence between floating mark and terrain? How distinctly can I see the sculptured surface of the terrain and appreciate (or measure, for that matter) differences in height; in other words,

† According to the revised MANUAL OF PHOTOGRAMMETRY.

what is the height error of the visual scanning procedure and on what factors does it depend?

Every Multiplex operator knows that he can recognize and appreciate the relief, the up and down of the earth's surface, much more clearly and distinctly on his tracing table than he could when looking down from the airplane at the real terrain. Therefore, quite justly, he will call the more distinct relief of the visual model an "exaggerated" relief. Analyzing the factors which cause this effect, and trying to find an expression for the amount of this "exaggeration," he will find that the determining factor is an increase of retinal disparity (or angular differential parallax) per unit height difference on the ground, which is the result of using a large air base instead of the small eye base. Expressing retinal disparity in terms more familiar to the photogrammetrist, and accounting for other minor factors, one will find by straight forward geometry that

$$\text{“exaggeration of relief”} = \frac{\text{air base}}{\text{eye base}} \times \frac{\text{final principal distance}}{\text{actual viewing distance}}. \quad (1)$$

In this equation, final principal distance means the principal distance* of the picture or optical image we actually look at, e.g. a contact print or reduced print under a stereoscope, a projection on a screen, or the last optical image formed in an optical viewing system before the rays enter the eye piece. Actual viewing distance means the distance from the plane of this final picture or optical image to the entrance pupil of the eye or of the combination eye and eye piece. The eye piece, whether a simple magnifying lens in a pocket stereoscope, or an elaborate piece of optics in a high precision plotting machine, is in this connection nothing but a device to permit, at a certain viewing distance, vision within the range of accommodation.

It should be mentioned here that the useful "exaggeration of relief" is of course limited by the resolving power of the pictures.†

The second term in equation (1) is equivalent to what is called the magnification M_i of a telescopic optical instrument, i.e. the ratio

$$M_i = \frac{\text{angle subtended by image of object at exit pupil}}{\text{angle subtended by object at entrance pupil}} \quad (2)$$

of this instrument.

Herewith, our term "exaggeration of relief" as defined by equation (1) becomes identical with the concept of "stereo-power"‡ of a stereoscopic telescope.

Much in contrast to the Multiplex operator's evaluation of the visual stereo model in terms of "stereo-power" is the viewpoint of the photo interpreter. When he uses a stereoscope, it is to get information about the shape of objects, about their tridimensional form. The "as if"-object he sees through his stereoscope, his visual model, is more often than not a distorted, deformed representation of the actual object.§ He will, under certain conditions, see normal houses appearing much higher in comparison to their length and breadth than they

* Principal distance is the perpendicular distance from the internal perspective center to the plane of a particular optical image, projection or finished photograph.

† See Aschenbrenner[1] for the relation between least detectible height difference and resolving power.

‡ Pulfrich, in his classical treatise on stereoscopic vision and measurement, coined the term "Totale Plastik" for this concept.

§ See Aschenbrenner[2] in Bibliography.

actually are, more resembling a sky scraper than a normal house of cubelike structure. Since recognizing height in vertical air photographs means recognizing relief, recognizing the third dimension in addition to horizontal length and breadth, the photo interpreter will quite justly blame his visual model to show "exaggeration of relief" if it makes houses (and other objects) appear higher in proportion to their horizontal dimensions as they actually are.

This effect is quantitatively described by the equation

$$\text{“exaggeration of relief”} = \frac{\text{convergency in object space}}{\text{convergency in image space}} = \frac{\theta}{\theta'}, \tag{3}$$

where θ and θ' are the base/height ratios in object and image space, namely (in the case of verticals)

$$\theta = \frac{\text{air base}}{\text{flying height}}, \tag{4}$$

and

$$\theta' = \frac{\text{eye base}}{\text{visual model distance}} = \frac{\text{eye base} - \text{separation}}{\text{actual viewing distance}}. \tag{5}$$

In the latter equation, separation means the distance from an image point in the left image to the corresponding image point in the right image, and is counted positive if the right image point lies to the right of the left image point (the opposite case, separation negative, may be realized in a stereo projection; the visual model would then appear before the screen).

With the values for θ and θ' just obtained we can rewrite equation (3):

$$\text{“exaggeration of relief”} = \frac{\text{air base}}{\text{flying height}} \times \frac{\text{actual viewing distance}}{\text{eye base} - \text{separation}}. \tag{3a}$$

With equation (3a) we have arrived at the photo interpreter's definition of "exaggeration of relief," which is radically different from the one derived by following the reasoning of the Multiplex operator (equation (1)). To the Multiplex operator, "exaggeration of relief" was a measure of the *distinctness of relief* regardless of relief deformation, whereas to the photo interpreter the same words mean a *measure of relief deformation* regardless of its distinctness.

Therefore, the term "exaggeration of relief" should be replaced by two different terms, each of which should be especially suited for expressing one or the other concept. The author invites suggestions from all photogrammetrists concerned, and offers as a tentative solution the following:

1. The effect described by equation (1) shall be called "*enhancement of relief*" instead of exaggeration, in order to avoid confusion with an exaggeration of linear dimensions. According to Webster's International Dictionary, enhanced means intensified with the implication of a raise in value or attractiveness. The quantity defined by equation (1) would conveniently be called "(relief) enhancement factor."

2. The effect described by equations (3) and (3a) shall be called "*relief stretching*" (*antonym "relief flattening"*), and the quantity defined by either of these equations would be the "(relief) stretching factor." The terms "stretched relief" and "flattened relief" seem to be ideally suited to describe the result in short and precise language.

With concepts and terms now sufficiently clarified, a brief review of some other presentations of the problem (see Bibliography) may be in order.

Salzmann[7] may be regarded as an eloquent advocate of the Multiplex operator's cause. His reasoning and results are in complete agreement with the line of thought which led us to equation (1). The photo interpreter's point of view, however, is summarily dismissed as "fallacious reasoning."

Beltman[3] seems to think of a stereo model in the sense of instrument model only, denying by implication the existence of a well defined visual model and emphasizing the ability of some observers including himself to perceive a stereo image with the eyes forced into unnatural directions and states of accommodation. This shall not be disputed, since it pertains to the second, highly personal phase of vision, i.e. the interpretation of retinal and muscular stimuli by the brain.

He follows Salzman[7] in arguing that "depth impression" (used in the sense of relief enhancement) decreases when the actual viewing distance is increased, which is right. But when he continues that in the same case geometrical construction would suggest—fallaciously, as he implies—an increase of "depth impression," he overlooks that at this point he is talking about a different kind of "depth impression," i.e. stretching or flattening the relief.

Wood,[8] in contrast to the above mentioned two authors, applies the term "exaggeration" in the photo interpreter's sense only—meaning relief stretching. According to the introductory nature of his article, he restricts himself to giving a very clear general explanation of this concept without going into detail or mentioning the other side of the problem.

Kistler[4] gives an extensive treatment of stereoscopy. The effect of relief stretching and flattening is called "stereoscopic distortion." Unfortunately, his treatment seems to be based upon the rather unrealistic assumption that the model distance is equal to the viewing distance. The effect of the separation of the two pictures or the amount of relief stretching is thereby completely neglected. His formula for computing the amount of "vertical distortion." i.e. the relief stretching factor, is therefore of limited value.

In other respects, this article contains some very valuable remarks concerning the effect of psychological factors and visual experience on the mental interpretation of the visual model. In this connection the concept of relief enhancement is also touched upon, but not analyzed.

Nowicki[6] clearly states the two different concepts in question. He explains "artificial enhancement of the power of stereoscopic vision" and also the term "stereo power" of a binocular instrument. Later in his article he deals with the effect of relief stretching and mentions as the cause the use of a viewing convergency (θ') which is not equal to the original convergency (θ). No comprehensive analysis of either concept is given.

McNeil[5] presents the geometry of the visual model as based upon the same unrealistic assumption which was used by Kistler,[4] i.e. zero separation of left and right picture. However, the effect of viewing distance on relief stretching (here called "vertical distortion" and "exaggerated—or flattened—relief effect") is correctly stated. The concept of relief enhancement is mentioned under the term "relief appreciation," but not explained. In an enumeration of factors affecting "relief appreciation" one finds two which do not belong there: "Decrease of flying height" affects resolution of depth* rather than relief enhancement, and "increase of separation of the photographs" affects relief stretching (cf. equation (3a)) but not relief enhancement.

The most important conclusion to be drawn from this review of facts and

* See Aschenbrenner[1].

terms seems to be that efforts toward a clear and unmistakable terminology should never weaken if we are to maintain a fruitful exchange of ideas and experiences, and to facilitate the training of scores of new photogrammetrists and photo interpreters.

A second conclusion: If we compare the solid, impersonal structure of an instrument model, in a Multiplex for instance, with the evasive, distorted form of a visual model under a stereoscope, we realize that the weakest point of visual stereoscopy is metric information. This is the domain of measuring instruments. Estimating heights and slopes from the visual stereoscopic model cannot be expected to give more than very crude values. An old shepherd or a young boy scout may be able to tell you the time from the behavior of the sheep or the shadow of trees, but you can do much better by looking at a watch.

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COMMENTS ON "THE INTERPRETATION OF TRI-DIMENSIONAL FORM FROM STEREO PICTURES"*

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GEOMETRICAL reconstructions such as in Figure 4 of the abovementioned paper are very useful when discussing the formation of the stereo-model by intersection of identical light rays in instruments like the Multiplex. Unfortunately those reconstructions may lead to faulty conclusions when discussing depth perception.

Even though in natural vision the ability of our eyes to converge and to accommodate appears to be interrelated, there are many observers, the author included, who are able to accommodate on near or far objects with the lines of sight parallel or even divergent. When viewing a pair of stereo photographs with the lines of sight in these positions, a stereo image is seen but not at infinity or, in the second case, behind the back of the observer, as geometrical reconstruction would suggest.

It has already often been stated,—for instance by Salzman in "Note on Stereoscopy" (PHOTOGRAMMETRIC ENGINEERING, 1950, p. 475), that depth perception is a function of retinal disparity.

In order to uncouple any undesired train of thought between the geometry of a stereo-model and human depth perception by the unaided eyes, it is prefer-

* The author of this paper was Dr. C. M. Aschenbrenner. See PHOTOGRAMMETRIC ENGINEERING, Vol. XVIII, No. 3, pp. 469–472.