*A Preliminary Study of the Influence of Photo Paper Characteristics upon Stereo Image Perception**†

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ABSTRACT: *In this study, six stereo pairs of photographs, each representing a different emulsion-surface-tone combination, were printed from the same negatives. Five well-trained forest photo interpreters performed parallax difference measurements of trees, tree crown counts and rendered personal evaluations on each. The results of the crown counts, in particular, point out some interesting relationships between photo paper characteristics and the comparative number of photo images perceived with the different stereo pairs.*

INTRODUCTION

IN VIEW of the information losses invariably taking place between the time of exposing the film in the aerial camera and completing the final paper print, every precaution must be taken to hold these losses at a minimum. It is currently possible, however, to exert only limited print quality control in view of the lack of available information—not only as to what factors govern these losses, but what their relative influences are. This study was designed as a preliminary step toward providing such information and involved a test of the influences of photo paper surface, emulsion and tone upon photo image quality. Only one set of negative conditions was tested: excellent quality 1:15,840 scale fall panchromatic photography of a forested area in northern Minnesota which presented a wide range of tree species, size classes and crown cover densities. This photography was flown in 1954 by Mark Hurd Aerial Surveys, Inc. of Minneapolis.

APPROACH TO THE PROBLEM

Most foresters specify a semi-matte paper in order to obtain a photo interpretation print which can be legibly written upon and which will withstand handling in the field. This use of a dull-surfaced paper, of which there are a number available, is perhaps the basis for a serious information loss. These photo interpretation prints are almost invariably processed to give a cold (blue-black) tone, which is considered to give the most normal print. Whether or not other tones are definitely inferior was not apparent in any of the literature examined.

Should variations in photo image quality actually exist between prints having differing surface-emulsion-tone combinations, it was felt that these variations would be expressed by variations in two characteristics of the photo images: (a) relative parallax, and (b) relative clarity of the tonal edge. It was further assumed that these variations could be detected by means of comparative parallax difference measurements and tree crown counts, respectively. In addition, since most experienced photo interpreters develop definite preferences when exposed to prints developed on a variety of papers, these preferences might well be a direct reflection of photo image quality. Should such be the case, then similar personal

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judgments rendered by a number of interpreters could well provide a means for photo quality classification.

Development of the Study

Preliminary tests of a number of commercially-available parallax bars were made under a Comparator until one was found which was deemed to be sufficiently accurate for the test. Conventional methods of lighting, however, left much to be desired due to the inability to maintain constant lighting, and the undesirable glare and parallax bar dot-shadow caused by low-angle frontal lighting. This was overcome by the construction of a special lighting system (Figure 1).

A tree-count circle with a true ground radius of 81.4 feet at the scale of the photographs was designed and printed on glass plates. In referring to Figure 2, it will be noted that the circle is divided into narrow columns to facilitate counting. To remove edge effects, all tree crowns bisected by a line on the -*I*- side of the axis arrow are thrown toward the center and counted in the column in which they fall. All tree crowns bisected by a line on the -*O*- side of the axis arrow are thrown away from the center of the circle and counted in the column in which they fall, or are thrown out of the circle, as the case may be. The axis arrow permits randomization of orientation in terms of azimuth turned from north, thus eliminating comparison with previous column counts. In actual practice, the transparencies are used stereoscopically in pairs with the center dot of the circles over the pin-prick in the plot center.

Five forestry graduates volunteered to undergo training and perform the tests, and all were subjected to a rigidly-controlled training program consisting of the following phases:

1. Orientation in equipment use: 1.5 hours per man.
2. Twelve parallax-difference measure-

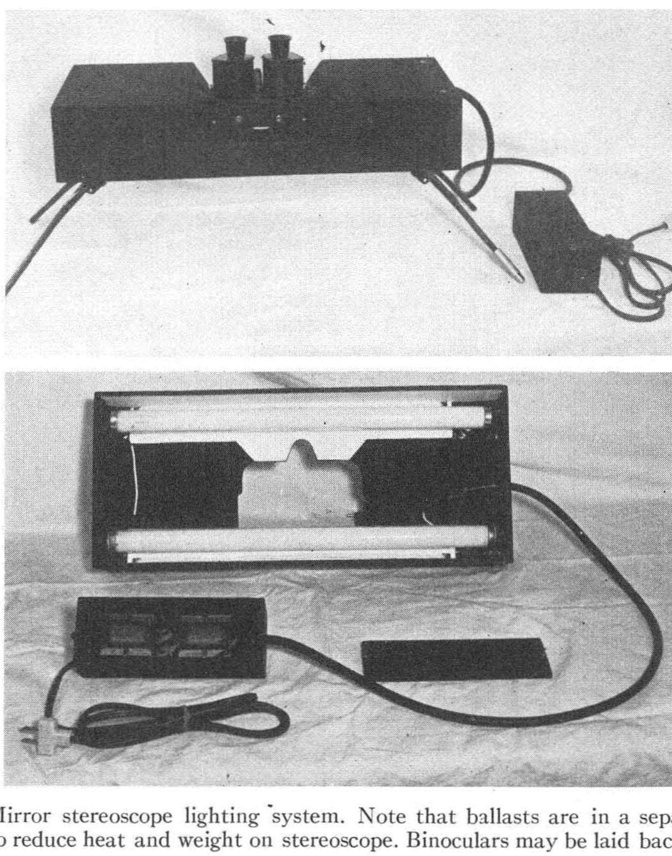

Fig. 1. Mirror stereoscope lighting system. Note that ballasts are in a separate ventilated box in order to reduce heat and weight on stereoscope. Binoculars may be laid back to permit 1:1 viewing.

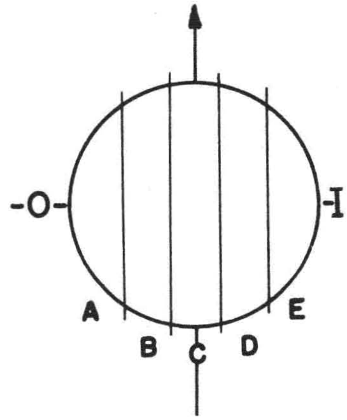

FIG. 2. Tree count transparency diagram.

ments of each of 19 practice trees whose true heights were known to the interpreters: 13.5 hours per man (average).

3. Six parallax-difference measurements of each of 45 practice trees whose true heights were not known to the interpreters: 13.5 hours per man (average).
4. Orientation in the use of tree count circles: 1.0 hour per man.

In order to select a suitable contrast to be employed as a standard in the printing of the test photos, the negatives covering the test area were printed on glossy papers having a range of contrasts from 1 through 4. These stereo pairs, without identification, were submitted to four experienced forest photo interpreters, not involved in the project, who examined them under the stereoscope. The majority selected the photo pair on 2 contrast paper (slightly flat in this case), and this pair was sent to the laboratory to serve as a guide in printing the test photographs.

The time available permitted the testing of only six different emulsion-surface-tone combinations. Those finally selected are described in Table I and were printed from the test area negatives under carefully-controlled laboratory conditions.

The parallax-difference measurement test was based upon 24 normal-crowned, dominant or co-dominant trees. These trees included two hardwoods, two pines and two swamp conifers in each of four height classes: 32–40, 40–48, 48–56 and 56–64 feet. All measurements in the field were made with a transit, and the trees

TABLE I

DESCRIPTION OF TEST PHOTOS

Photo paper code letter	Description		
	Emulsion	Surface	Tone
A	u	glossy	cold (blue-black)
B	v	glossy	warm (brown)
C	w	semi-glossy	cold (blue-black)
D	x	semi-matte	cold (blue-black)
E	y	semi-matte	cold (blue-black)
F	z	semi-matte	cold (blue-black)

were numbered on the photographs and randomized, using a split-plot design in the following order: (a) interpreters, (b) species, and (c) photo papers. Each tree was measured three times (not consecutively) on each paper by each interpreter. In every case, the point to be used for the base reading was marked for each tree and provided for a wide variety of conditions (e.g., bare ground, grass cover, brush cover and canopy openings).

For the crown-count test, five plots 81.4 feet in radius were selected which, as a whole, were deemed to present the widest possible cross-section of such photo image characteristics as tone, texture, size, shape and pattern (Table II). Regardless of height or crown diameter, all trees considered to be exposed vertically were counted. Again, a split-plot design was used which provided for three replications (not consecutive) and randomization in the following order: (a) interpreters, (b) plots, (c) papers, and (d) azimuth orientation of the axis arrow in 20 degree units.

TABLE II

DESCRIPTION OF CROWN COUNT TEST PLOTS

Plot code no.	No. vertically exposed crowns	Species composition
1	263	Jack pine with scattered scotch pine
2	345	Black spruce
3	270	Aspen and paper birch with scattered jack pine
4	453	White pine with scattered jack pine
5	466	Norway pine

TABLE III

RESULTS OF ANALYSIS OF VARIANCE OF THE MEAN PERCENTAGE ERRORS INCURRED IN THE CROWN COUNT TEST

Source of variation	DF	Mean squares	F	Table value		Significance	
				5%	1%	5%	1%
Bet. interp.	4	360.1478	2.06	3.01	4.77		
Bet. plots	4	2,896.9365	16.55	3.01	4.77		Sig.
Exp. error (a)	16	175.0340					
Total (a)	24						
Bet. photos	5	139.8674	15.08	2.30	3.20		Sig.
Plots×photos	20	18.0405	1.94	1.68	2.06	Sig.	
Exp. error (b)	100	9.2779					
Total (b)	149						

RESULTS

A. THE PARALLAX-DIFFERENCE MEASUREMENT TEST

The mean parallax-difference measurement heights and errors of measurement in feet of the 24 test trees were computed, and these data, in various forms, were subjected to analyses of variance and *F* tests. In no case were any of the differences between the photographic papers tested found to be significant.

B. THE CROWN COUNT TEST

The crown-count errors (all were negative) were expressed as a percent of the true number of crowns exposed on the plots. These percentages were then averaged for the three replications and these results (Figure 3) subjected to analysis of variance (Table III) and *t* tests (Tables IV and V).

The *t* tests of the plots *x* photo papers interaction indicated the following points of interest: (a) the differences between photo papers by individual plots were not significant, and (b) the differences between plots by individual photo papers were significant—varying slightly in degree but having, in all cases, the same order of ranking from largest to smallest mean errors as that shown in Table V (i.e., 4-5-3-2-1-).

These relationships between the test photos may also be considered in terms of the numbers of crowns seen. A total of 1,797 crowns, considered to be exposed vertically at the time of photographic exposure, were counted on the ground in the five plots. A summary of the mean number of crowns actually recovered (seen) by the interpreters from the various papers is provided in Table VI. A comparison of this crown recovery pattern on a percentage basis (Table VII) is particularly worthy of note.

TABLE IV

TEST OF SIGNIFICANCE OF APPARENT DIFFERENCE IN MEAN PERCENTAGE CROWN COUNT ERRORS BETWEEN PLOTS

Plot No.	Plot Cover type	Mean error of count %	Differences in count error bet. plots 4	5	3	2
4	White pine with scattered jack pine	65.2				
5	Norway pine	59.2	6.0			
3	Aspen and paper birch with scattered jack pine	53.1	12.1**	6.1		
2	Black spruce	45.5	19.7**	13.7**	7.6*	
1	Jack pine with scattered scotch pine	41.0	24.2**	18.2**	12.1**	4.5

* Significant at the 5% level ($LSD_{.05}=7.25$).
** Significant at the 1% level ($LSD_{.01}=9.99$).

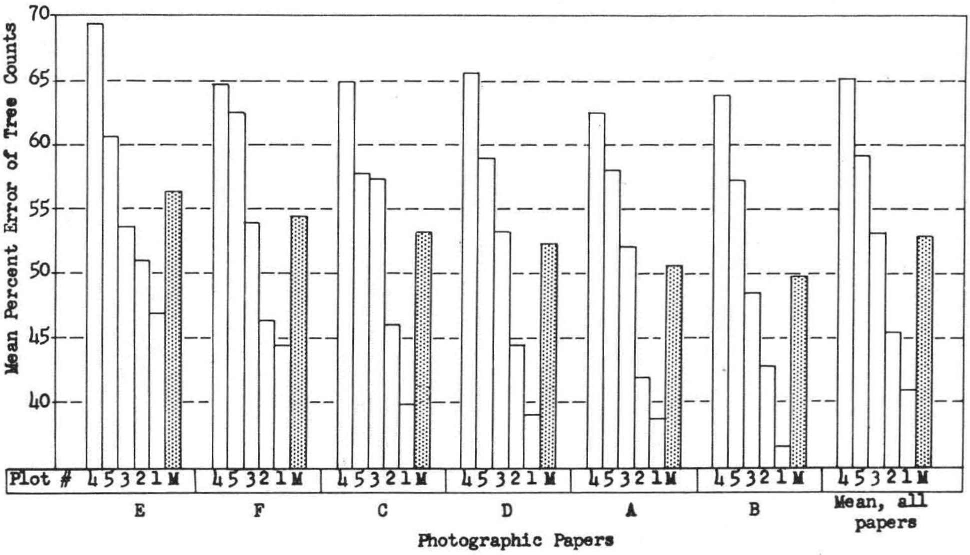

FIG. 3. Graphic summary of the mean errors incurred in the crown count test.

C. THE PERSONAL EVALUATION TEST

During the tests, each interpreter was required to keep a confidential diary into which he methodically, and in standard form, recorded his personal impressions of each test paper. Upon completion of these two tests, each scored the six test papers as either "Excellent" (4 points), "Good" (3 points), "Fair" (2 points), or "Poor" (1 point), in terms of the following qualities: (a) lack of eyestrain, (b) confidence in base readings, (c) ability to perceive tips of confers, (d) ability to perceive tips of hardwoods, (e) ability to perceive individual conifers, and (f) ability to perceive individual hardwoods. After the parallax difference measurement and crown-count tests had been completed, this rating was accomplished independently by each interpreter.

These evaluations agreed with the crown-count test results to the extent of the following: (a) papers *B* and *E* were unanimously selected as the best and poorest, respectively, (b) the majority selected paper *A* as second best, and (c) papers *C*, *D* and *F*, as a group, were scored as being intermediate in quality between papers *A* and *E*. These latter three papers received nearly the same average numerical scores, but their relative positions were subject to great diversity of opinion among the individual interpreters. Apparently the average interpreter can only utilize his per-

TABLE V

TEST OF SIGNIFICANCE OF APPARENT DIFFERENCE IN MEAN PERCENTAGE CROWN COUNT ERRORS BETWEEN PHOTOS

Photo paper	Description	Mean error of count (%)	Difference in count error between papers				
			E	F	C	D	A
E	semi-matte, cold	56.2					
F	semi-matte, cold	54.4	1.8*				
C	semi-glossy, cold	53.2	3.0**	1.2			
D	semi-matte, cold	52.4	3.8**	2.0*	0.8		
A	glossy, cold	50.8	5.4**	3.6**	2.4**	1.6	
B	glossy, warm	49.8	6.4**	4.6**	3.4**	2.6**	1.0

* Significant at the 5% level ($LSD_{.05}=1.71$).
** Significant at the 1% level ($LSD_{.01}=2.26$).

TABLE VI

MEAN NUMBER OF TREE CROWNS SEEN BY INDIVIDUAL INTERPRETERS ON THE DIFFERENT PHOTO PAPERS (OUT OF A TOTAL OF 1,797 COUNTED ON THE GROUND)

Photo interp.	Photo paper					
	B	A	D	C	F	E
I	876	837	822	783	748	727
II	858	879	836	874	840	854
III	892	885	823	823	796	754
IV	931	920	873	871	859	778
V	774	753	765	720	707	674
Total	4,331	4,274	4,119	4,071	3,950	3,787
Mean	866	855	824	814	790	757

TABLE VII

COMPARISON OF THE VARIOUS PHOTO PAPERS FROM THE STANDPOINT OF PER CENT OF PHOTO IMAGES RECOVERED (SEEN)

Photo paper	Description	Mean comparative percentage of total tree crowns recovered (seen) by five photo interpreters	
B	glossy, warm tone	recovered 1.3% more tree crowns than paper	A
		5.1	D
		6.4	C
		9.6	F
		14.4	E
A	glossy, cold tone	recovered 3.8% more tree crowns than paper	D
		5.0	C
		8.2	F
		12.9	E
D	semi-matte, cold tone	recovered 1.2% more tree crowns than paper	C
		4.3	F
		8.9	E
C	semi-glossy, cold tone	recovered 3.0% more tree crowns than paper	F
		7.5	E
F	semi-matte, cold tone	recovered 4.4% more tree crowns than paper	E
E	semi-matte, cold tone	least tree crown recovery of any paper used	

sonal reactions for selecting the extremes in print quality.

CONCLUSION

The higher degree of success in tree crown-counts experienced with the glossy-surfaced papers, as compared to the dull-surfaced papers, was expected. What was not anticipated, however, was the relatively small margin which, as a whole, existed between the two types of surfaces. For instance, in terms of papers having the normal blue-black cold tone, the use of a glossy surface resulted in a mean recovery of only 3.8 per cent more trees crowns than was obtained with the most successful dull-surfaced paper (a semi-matte)—a difference which was not significant statistically. Admittedly, however, this same cold tone glossy-surfaced paper produced a mean recovery of 12.9 per cent more tree crowns than the least successful dull-surfaced paper—a difference which statistically was significant at the one per cent level. This is considered to be a serious loss of information and seems to indicate that all emulsions do not produce photo images of the same quality even though the contrasts, tones and surfaces are the same. For the conditions tested, therefore, it would appear that the photo image loss incurred by using a cold tone semi-matte print in lieu of a cold tone glossy print can be held at a very narrow margin by proper choice of emulsion.

The true role of the warm (light brown) tone as such in the results of these tests is difficult to assess. Certainly the glossy prints in which it was included proved superior to any of the papers tested. Perhaps fully as interesting as its numerical superiority in terms of tree crown-count success was the enthusiasm it created among the interpreters. Without exception, and in no uncertain terms, they all considered it superior—not only because of the apparent relative lack of eye fatigue, but also from the standpoint of a feeling of complete confidence that more photo images were visible and that these images, individually, were more sharply defined. Whether or not the introduction of such a tone in the semi-matte papers would result in an increase in image perception over what is obtained with a cold tone is a moot question; this may be answered by tests now being conducted.

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Remarks on Lens Distortion

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A RECENT paper by Mr. James G. Lewis, U. S. Geological Survey* shows lens distortion as a variation of the focal length in terms of the angle of field, and presents it as "a new look at lens distortion." May I point out that in France this method has been used for over twenty years, very successfully. It was described in a long paper I delivered to the VIth International Congress for Photogrammetry (The Hague 1948), entitled "Méthodes de Contrôle des objectifs photogrammetriques, des appareils de prise de vues et des surfaces sensibles en usage à l'Institut Géographique National," quoted by Dr. Francis E. Washer in the Sept. 1956 issue of PHOTOGRAMMETRIC ENGINEERING and which is to be found in Tome X, First Part of the International Archives of Photogrammetry, published by N. V. Wed. J. Ahrend en Zoon, Amsterdam. This method has been adopted by Prof. Ingelstam, of Stockholm, for the Swedish Government, after he visited our organization in Paris, in 1950. On several occasions, Prof. E. H. Thompson evidenced his great interest. A similar method for representing distortion was indicated by Dr. Le Divelec in a paper delivered in Washington (1952).

My main intention, in sending this note to the Editor of PHOTOGRAMMETRIC ENGINEERING, is not to bring up a question of priority but to present two features which seem to be of interest.

Representation of distortion as a variation of the focal length, according to the angle of field, seems to be the only way of expressing the measurement of a quantity directly bound to distortion (a distance on the plate) in terms of another measured quantity (an angle of field in the object space), without assuming anything about the focal length (as, for in-

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