POTENTIALS OF MONOCULAR AND STEREOSCOPIC OBSERVATIONS ON AERIAL PHOTOGRAPHS

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Abstract

Precisions of measurement of X, Y and Z coordinates on aerial photography are discussed in relation to the parameters of image quality, optical magnification and target characteristics. The potential precisions that can be obtained using high image quality photography and high optical magnification are then given. Precisions currently possible on aerial photography are compared with accuracies now being obtained with camera calibration and block adjustment. It is concluded that even though accuracies of block adjustment at present are larger that measuring precisions, improvements in measuring precisions will be necessary if accuracies of block adjustment are to improve.

1. Introduction

The visual tasks of monocular and stereoscopic measurements have been studied in detail over the past decade, Trinder (1971, 1973, 1982, 1984a, 1984b). The purpose of the study was primarily to analyse the parameters of the image, such as image quality and description of the ground target, and those of the observation system that affect the performance of these visual tasks. Results of the study should provide information on the aspects which must be addressed if improvements in the overall accuracy of the photogrammetric process are to be achieved. Such improvements will ultimately lead to an increase in the efficiency of photogrammetry.

The study commenced with an investigation of the fundamental parameters affecting the precisions, using laboratory test equipment and images. The images were subjected to various levels of blur and noise so that a full range of values of these parameters could be investigated. Subsequently, aerial photography of ground targets was obtained to confirm the results of the laboratory studies. Image quality of the photography was measured and monocular and stereoscopic pointing precisions obtained from observations on the targets. Conclusions derived from these studies have been given in Trinder (1984a), for monocular pointing precisions, that is, precisions of observations in the X and Y directions in the stereoplotter. Even though the observations were made monocularly, it has been well established that monocular and binocular (as opposed to stereoscopic) observations result in the same pointing precisions. In Trinder (1984b) are given conclusions with respect to stereoscopic observations. Both papers make recommendations on the optimum optical magnification to be used during observations, optimum target sizes and shapes, and comment on the potential pointing precisions that can be achieved compared with those which are currently possible. This paper will summarise those results, and relate them to current accuracies which are being achieved in photogrammetric block adjustment and camera calibration.

2. Research

The project investigated the following aspects:-

2.1 Target characteristics

Factors studied were size, shape and colour.

2.2 Image quality of the photography

A loss in imaging quality of an optical system will result in blurred images of ground features which are clearly more difficult to measure to than high quality sharp images. The task of this study was to derived a parameter of image quality of blurred targets which could be easily related to observer performance. The image quality parameter which proved to be suitable was the slope of the density profile of the target. This parameter was easily measured on the observed target, and indeed a logical choice considering the task of an observer. Slope of the density profile was expressed in units of ΔD/mrad, where ΔD is the density difference of the blurred profile and mrad, is the angular subtense of the linear dimension of the target edge.A conversion from mrad to μ at a known optical magnification is derived from the formula :- mrad=μ x optical magnification/250.

The relationship between slope of the density profile and commonly used parameters of image quality, such as spread functions and MTF's was determined by extensive computations involving convolutions of MTF's of various Gaussian spread functions with different targets. The results of these computations enabled a direct relationship to be determined between image quality in terms of spread functions and MTF, and pointing precisions.

A Gaussian spread function was chosen because the computations are lengthy, and a general image quality measure was required which would describe image quality of various systems with close approximation. It can be shown that the spread functions of photogrammetric systems closely approximate Gaussian curves. An additional advantage of a Gaussian function is that it can be described by one parameter σ.A typical Gaussian spread function is shown in Figure 1. The conversion from spread function 2σ value to MTF is shown graphically in Trinder (1984) while the relationship between frequency limit (FL) and 2σ is summarized in Figure 2.

2.3 Photographic Noise

Photographic noise has been described by Signal to Noise Ratio (SNR) defined as the ratio of the density difference Δ of the target above background over the RMS granularity derived with an aperture equivalent to 48μm for an optical magnification of 12x. The effects of noise to an observer increase as optical magnification increases since the effective scanning aperture of the eye on the viewed image decreases with magnification, i.e. RMS granularity is inversely proportional to optical magnification. The studies have shown that noise affects precision as SNR drops below about 5, which for normal aerial photographic materials, with an RMS granularity of less than 0.03ΔD for an aperture of 48μm and gross density of 1.0, would occur for magnification greater than 30x, with high contrast targets e.g. 5:1. RMS granularity of colour photography is much less than that of black-and-white photography, and therefore noise on colour photography will not influence visual observations.

2.4 Optical magnification was studied in two contexts:-

(i) given a fixed optical magnification, what targets should be selected, and what precision should result from observations of the targets in X, Y and Z directions?

(ii) given the possibility of a variable optical magnification, what magnification should be selected for the image quality of the photography? This optimum magnification should then result in the overall best pointing precision in X, Y and Z obtainable for that photography.

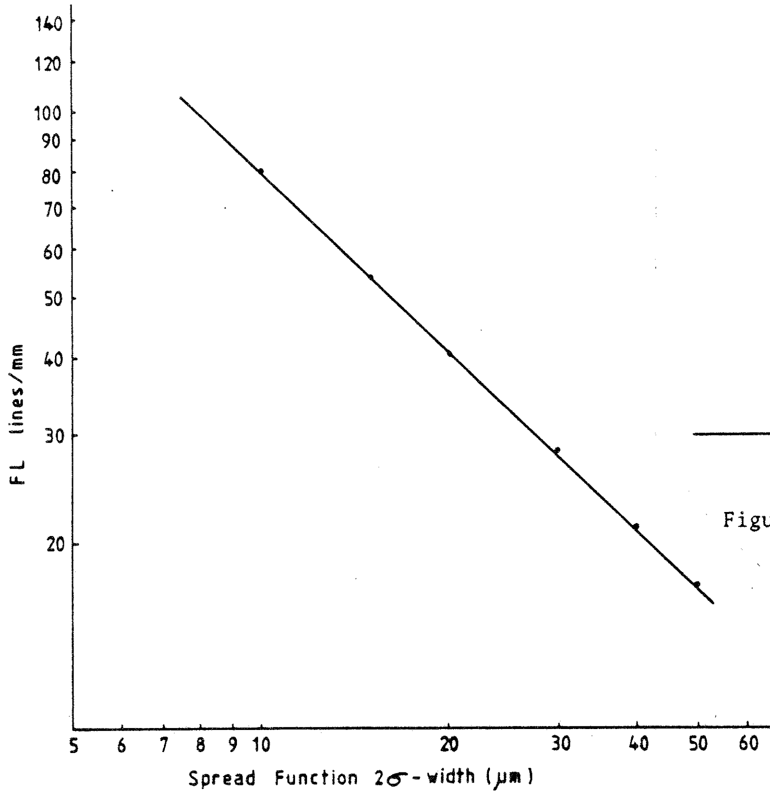
3. Summary of the Results of the Observations

3.1 Characteristics of monocular and stereoscopic observations

Before detailing the results, it is relevant to describe the fundamental difference between monocular and stereoscopic observations. The task of placing a measuring mark in the centre of circular or cross-type target involves equating two sections of the target on either side of the measuring mark. This process is referred to as a vernier acuity task, and is fundamentally the same whether the target is a circle or a cross. The precision of achieving that task will be the same whether the target is viewed monocularly, binocularly, or indeed in a stereoscopic model in which X and Y coordinates are being measured.

Stereoscopic observations are dependent on the task of X-parallax (also referred to as retinal disparity) clearance in which the difference in the locations of the two images in the visual system with respect to a reference mark are eliminated. X-parallax clearance is dependent on distinguishing features of the target which can be used for its elimination. The boundaries of the target are the features used rather than its overall size or shape.

Because the processes of vernier acuity and X-parallax clearance are fundamentally different tasks, it can be expected that a significantly different pattern of results will be obtained for the two tasks. For monocular observations, precisions are dependent on target size; for stereoscopic observations this is not the case. In Figure 3 is shown the precisions of pointing to circular and cross-type targets, and X-parallax clearance observed on black-and-white aerial photograhy; the precisions of X-parallax clearance were computed from the height precisions derived in the observations. The parameter on the abscissa scale is annulus width for circular targets, and the distance between the edge of the measuring mark and the end of the crosses, for cross-type targets, while the ordinate scale is pointing precision. Both scales, are expressed in circular measure and linear dimensions for 6x optical magnification.



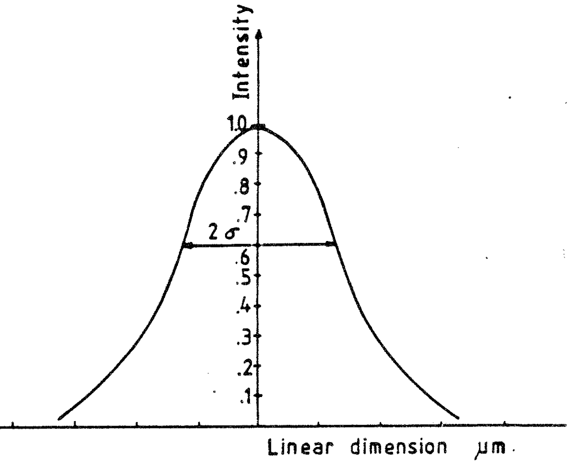


Figure 1: Gaussian Spread Functions.

Figure No. 2: Relationship between Gaussian spread function 2σ - width and Frequency Limit (FL).

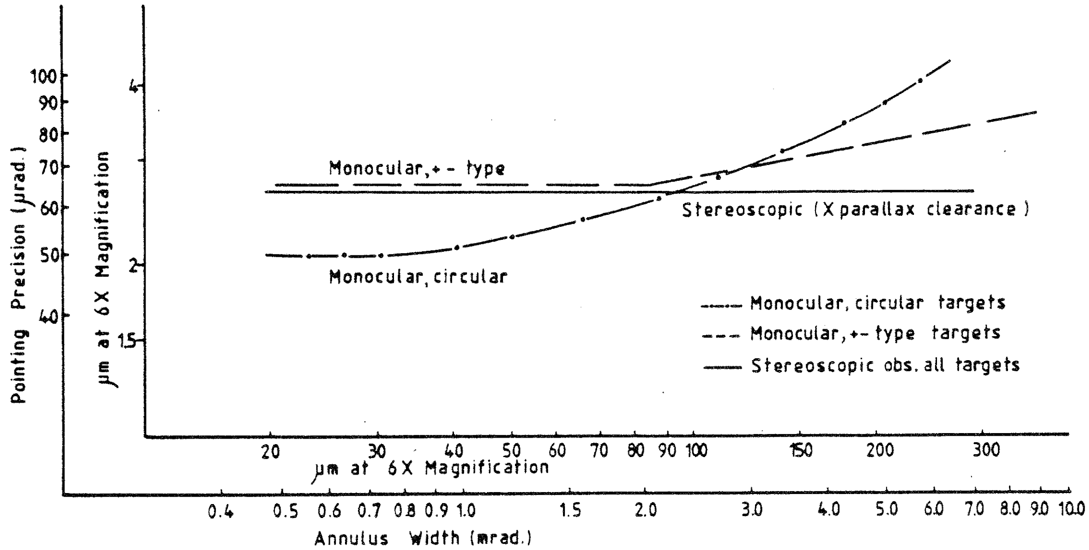


Figure 3. Precisions of Monocular Pointing and X-parallax Clearance for circular and cross-type targets. Dimensions are expressed as angular subtense and linear dimension for an optical magnification of 6X.

3.2 Significant Target Parameters for Monocular Observations

The investigations indicated that pointing precisions are far more affected by blur in the image than noise. Noise will not affect observations unless the target contrast is very low, or optical magnification is very high. As expressed earlier, the SNR is generally well above the critical value of about 5. Image quality of negative aerial photography tested expressed as a Gaussian spread function varied between 2σ-widths of 14μm and 24μm (FL ranging from 57 lines/mm to 34 lines/mm). Positive images had Gaussian spread function widths ranging from 23μm to 28μm (FL ranging from 36 lines/mm to 30 lines/mm. The above figures describe the range of image qualities from wide angle to super-wide angle and for different positions on the image plane. The difference in image quality of super-wide photography compared with wide angle photography was of the order of 5μm in spread function width. Trinder (1984a) therefore predicted that the pointing precision for optimum size ground targets on this photography would be of the order of 1.5 to 2σ for an optimum optical magnification of about 24x. For best results, the target should be circular varying between 100μm and 140μm in size depending on image quality, assuming a measuring mark of 60μm in diameter. For smaller measuring marks, the target size should be reduced by 1/2 the difference between the size of the measuring mark used and 60μm.

The relationship between optical magnification, image quality and target sizes is demonstrated in Table 1 where it is revealed that if image quality improves such that the spread function 2σ width is 10μm (FL of 80 lines/mm) a pointing precision better than 1μm is possible at optical magnifications greater than 24x.

TABLE 1: Optimum Target Sizes and Precisions (μm)

Optical Magnification 2σ-width of sp. fn. (μm)	FL lines/mm	6x		12x		24x		36x	
		Targ. Size	Prec.	Targ. Size	Prec.	Targ. Size	Prec.	Targ. Size	Prec.
10	80	100	1.3	80	0.9	80	0.7	80	0.6
20	40	120	2.0	100	1.4	100	1.3	100	1.1
30	28	180	2.6	150	2.1	140	2.0	-	-

Circular targets tend to be expensive to lay because as well as the target itself, a background also has to be laid. Therefore many mapping organisations choose the cross-type target which, although the resulting pointing precisions are marginally higher, will require less material. The target colour which has proved to be suitable in many mapping organisations is yellow on a black background. Though plastic materials were used for this study, a mat surface is preferred.

In this study, it is significant that pointing precisions on colour photography were consistently about 20% higher than those obtained on black-and-white photography. This is contrary to previously held views, but was confirmed by a large number of carefully controlled observations on many targets. As revealed later, it occurred also for heighting observations. There appears therefore to be no doubt about this claim.

To summarise, the highest precision of pointing in X and Y directions can be achieved by using colour photography, observed under magnifications of about 24x. The precision would then be about 1.5 to 2μm for circular and cross-type targets depending on the image quality of the photographic system used. Potentials are, however, that if the image quality can be improved by a factor of about 2, in terms of spread function width, pointing precisions could be better than 1μm providing sufficiently precise equipment is available to reveal such precisions.

3.3 Stereoscopic Heighting

Stereoscopic heighting i.e. determination of the Z-coordinate presents fewer complications than do the observations of X and Y coordinates. Because stereoscopic heighting is a process of X-parallax clearance, based on the borders of the object viewed, neither shape nor size has a significant influence on heighting precision. Precisions approached 0.03 pro mille of the projection distance for the observations made in Trinder (1984b) at 6x optical magnification, but under high magnification it was estimated that precisions could be of the order of 0.02 pro mille of the flying height (precision of X-parallax clearance of 1.8μm). On colour photography, precisions were higher than those on black-and-white photography by about 20%, reflecting the same improvement as was obtained for monocular observations. A study of precisions on super-wide angle and wide angle photography showed that superior heighting precisions should be obtained on super-wide angle photography compared with those on wide angle photography of the same scale because of the better base/height ratio of super-wide angle photography. The difference in image quality of super-wide angle photography compared with that of wide angle photography was insufficient to affect heighting precisions.

The effects of a deterioration in image quality will influence heighting measurements more than monocular pointing (Trinder, 1972). However, it was shown that for standard aerial photography, observations could be made at optical magnifications up to 24x without serious deterioration in precision. In addition, it was deduced that for images, for which the Gaussian spread function 2σ width is of the order of 20-30μm (FL varying from 40 to 28 lines/mm) heighting precisions could be as small as 0.015 pro mille to 0.02 pro mille of the flying height if viewed under high magnification (precision of X-parallax clearance of 1.4 to 1.8μm). For images whose spread function 2σ-width is 10μm (FL of 80 lines/mm), heighting precisions could be as small as 0.01 pro mille of the flying height (precision of X-parallax clearance of less than 1μm) or better if viewed under high optical magnification.

To summarise, the best heighting precision can be achieved using colour photography observed under magnifications of about 24x. The precision would be of the order 0.02 pro mille flying height. Potentially, if the image quality of photography can be improved by a factor 2 in terms of spread function width, heighting precisions could be 0.01 pro mille of the flying height or better.

4. Relationship of Potential Precision to Practical Results in Photography

It is relevant to relate the precisions revealed above to those that are being achieved with photogrammetric block adjustment, and camera calibration, to determine whether image quality is currently a limiting factor in the precision of photogrammetry. If it is, then image quality must be an element of the photogrammetric process pinpointed for improvement.

Hakkarainen (1983) showed that camera calibration using goniometer methods can determine radial lens distortion values to an accuracy of 2μm and mean radial distortion to 1μm. Tangential distortion can be determined to an accuracy of better than 1μm. Carman and Brown (1978)describing the N.R.C. camera calibration facility indicated that average radial measured distortion in aerial cameras remained constant to 1 to 1.5μm. These same figures reflect the accuracy of the calibration procedure. Ziemann (1978) has indicated that reseau crosses can be measured on comparators to an accuracy of 1μm while comparators are also accurate to about 1μm. Ziemann (1982) has shown that the pointing precisions on calibration images were of the order 2.2 to 3μm depending on the observer. This figure is consistent with those obtained by Trinder (1984) for low optical magnifications, but larger than can be obtained at high magnification. Ziemann also found that distortion derived by different calibration procedures varied by as much as 1-2μm. According to these figures potential measuring precisions on aerial photography are generally comparable with the accuracies of lens distortions derived from camera calibration.

Attempts to eliminate the unknown systematic errors in photograph geometry, have led over the last 10 years to the inclusion of addition parameters into block adjustment. Kilpela (1981) showed that accuracies of block adjustment with additional parameters using dense control on high precision test blocks, are of the order of 2.5μm to 4μm in X and Y and 4μm to 6μm in height (equivalent to X-parallax of 2.4μm to 3.6μm) or 0.026 to 0.04 pro mille flying height. Jacobsen (1982) obtained similar results but also achieved a precision of 1.5μm for X and Y and 2.7μm in height (0.018 pro mille flying height or 1.6μm X-parallax clearance) for a four-fold block of Jamijarvi. As control density decreases so do the accuracies of the block adjustment, especially height accuracies. Therefore, reference is made only to high density control blocks because they are indicative of obtainable precisions for block adjustment.

Kilpela's results indicate that there is still some difference between block adjustment accuracies and the precision of measurement and that observer capabilities for the observations on currently available photography are not yet the limiting factor. On the other hand, Jacobsen's accuracies have already reached the precisions which can be achieved by observers. Jacobsen's tests may be a special case of adjustments of a special data set, but they indicate the potentials of block adjustment methods. It is apparent that block adjustment techniques will require better precisions of observations of X, Y and Z coordinates in the future if accuracies are to continue improving. At the present time, these precisions are limited by the quality of the images, assuming that measuring equipment is sufficiently accurate.

Precisions of observations can be improved marginally by using colour photography, but greater improvements are needed in both camera lens quality and photographic materials if significant improvements in precisions are to be made. New cameras are being developed with image motion compensation while high resolution photographic materials are now also available. It is worth considering such equipment and facilities if the highest precision of measurement is being sought. Higher precisions will ultimately lead to more economic photogrammetric procedures.

5. Conclusions

The precisions of coordinates on currently available aerial photographs can reach 1.5 to 2μm in X and Y and 0.02 pro mille flying height in Z (precision of X-parallax clearance of 1.8μm) if high optical magnifications are used during observations. In photogrammetric block adjustments today, accuracies of planimetric and height approach these figures, though in many cases there is still some significant difference. However, pointing precisions are a significant component of the overall accuracy of photogrammetry, and should therefore be improved where possible. Improvements can be made by choosing the highest image quality lenses and photographic materials. However, manufacturers should be encouraged to develop even better image quality equipment and materials so that further improvements can be made in measuring precisions.

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