IMAGE EVALUATION FOR AERIAL PHOTOGRAPHIC AND MICROSCOPIC SYSTEMS

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P R E F A C E

This thesis consists of two parts. The first part deals with image evaluation for aerial photographic systems. The second part is concerned with image formation in microscopic systems.

PART I

The aerial photographic systems have two basic components, the lens and the film. For these, a number of image quality parameters have been proposed and used including the MTF, resolving power, acutance and the single bar response. The resolving power is the most widely used of them all. In a single figure of merit it takes into account a number of diverse factors such as overall system MTF, emulsion gamma and granularity and the response of visual system. A theoretical prediction of resolving power is difficult due to these very factors and considerable attention has been given to this problem in recent years* .

In the present work, a relationship between image modulation and object modulation for a general periodic or a truncated periodic object has been derived. It has been shown that image modulation bears, in general, a nonlinear relationship to object modulation so that the ratio of the two at a certain spatial frequency is dependent upon the latter. The results have been illustrated for the commonly employed resolving power targets,

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* G.C. Brock, Image Evaluation for Aerial Photography (Focal Press, London, 1970).

namely the tribar and the two-bar. The tribar response also depends upon the background irradiance level. Three cases have been considered; the irradiance level outside the target equal to - (a) minimum inside the target, (b) maximum inside the target and (c) mean level inside the target. It has been shown that the difference between square wave response and the tribar response is due primarily to the difference in mean irradiance levels in their images. The mean irradiance level $\bar{I}$ in the image of a tribar depends upon the background irradiance level and also upon the nature of system MTF at low spatial frequencies. The dependence of tribar response upon incident modulation is critically dependent upon the value of $\bar{I}$. The resolution for low-contrast resolving power targets of various forms for some representative systems has also been compared.

Some consequences of target contrast and background upon tribar threshold and resolution have been discussed. It has been shown that the usual tribar consisting of bright lines in a dark background yields spuriously large high-contrast resolution if the system has a poor low frequency response. By choosing an appropriate model for emulsion MTF, it has been shown that different combinations of a test lens aperture and the target contrast which produce the same aerial image modulation (AIM), produce different modulation in the effective exposure distribution (EEM). The implications of this fact in the measurement and application of emulsion thresholds have been discussed. The contrast dependence of the image transfer function[@] (ITF) defined

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@ R. Williams, Phot. Sci. Eng. 13, 252 (1969).

as the ratio of EEM to AIM has also been investigated.

The system response to a general two-bar pattern in which the widths of bright and dark spaces are not equal, has been investigated. The object is characterized by a parameter α such that $\alpha/(1-\alpha)$ represents the ratio of the width of one of the bars to the interval between the bars. The bars of the pattern may be brighter or darker than the background. The dependence of image contrast upon α for a fixed period of the target has been investigated and some interesting results about the reproducibility of two-bar pattern by aerial camera system have been brought out. Assuming a certain threshold contrast for resolution, the dependence of limiting spatial frequency upon α has been presented graphically which shows the transition from the Rayleigh limit of resolution ($\alpha \rightarrow 0$) to the usual two-bar resolution ($\alpha = 1/2$).

Finally, the use of single bar targets for photo-optical image evaluation has been investigated from a theoretical stand point. The single bar analysis provides a suitable basis for the description of image quality as a function of size for isolated details. When the image of a single bar is degraded by an optical system, the central intensity is reduced, the energy is diffracted outside of the region of geometric image and the transition between the two normally bright and dark regions of the image becomes more gradual. The most important image quality parameter based on the first effect is the relative contrast defined as the ratio of the central intensity in the image to that in the object. Two other parameters have been introduced: the variations of (a) thefraction of total energy contained in the area of the geometric image of the bar, (b) the gradient at the geometric image of one of the edges of the bar - both as functions of bar size. The significance of these parameters as frequency weighted averages of MTF has been brought out. Similar analysis has also been carried out for disc shaped objects which are more appropriate for the evaluation of rotationally non-symmetric systems. The results have been illustrated for pupils of non-uniform amplitude distribution and the micro-contrast characteristics of both apodizing and superresolving pupils have been compared with that of an Airy type pupil.

The effect of introducing a background level in the object irradiance distribution upon image modulation has been investigated. The contrast in the images of bars and lines of equal sizes has also been compared. The use of the bar image transfer function and the emulsion threshold for the prediction of detectability of isolated details, as proposed by Williams, has been re-examined.

PART II

In instruments like microscopes and microdensitometers, the object is illuminated by an auxiliary system consisting of an extended primary source and a system of condenser lenses. The illumination of the object under these conditions is partially coherent and the image forming properties of the system depend upon, among other factors, the coherence conditions prevailing upon the object plane.

A mathematical framework for treating the problem of image formation under partially coherent illumination has been provided by Hopkins[++]. In his theory, the illumination at the object plane is considered as due to an incoherent effective source such that the source irradiance distribution function and the mutual coherence function at the object plane form a Fourier transform pair in accordance to the van Cittert-Zernike theorem. Under certain conditions usually met in practice, the exit pupil of the condenser is illuminated incoherently and may be identified as the effective source. These conditions are satisfied when the image of the primary incoherent source is large as compared to the extent of the Fraunhoffer diffraction pattern of the condenser aperture. The appropriate formulae for image irradiance distribution in this case have been obtained by Hopkins. The state of coherence in the object plane is governed by a parameter ϱ defined as the ratio of the numerical aperture of the condenser to that of the objective, the coherent and the incoherent limits corresponding to $\varrho \to 0$ and to $\varrho \to \infty$ respectively.

When the primary source is not large enough to satisfy the above mentioned condition, the condenser aperture is partially coherently illuminated and the illumination at the object plane

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++ H.H. Hopkins, Proc. Roy. Soc. A 208, 263 (1951).

is non-uniform and spatially non-stationary. Hence, the concept of effective source is not valid in this case. Starting with the general equation for the propagation of mutual intensity from the primary source plane to the image plane through the various intermediate stages, and using the well-known Fourier transform relationships, a general equation for the image irradiance distribution has been derived. This expression reduces to that of Hopkins when the primary source is large.

The influence of condenser transmission characteristics upon the performance of microscopic systems has been investigated within the framework of Hopkins theory. Since the condenser aperture is incoherent, purely phase variations over it have no effect upon the images. However, if amplitude coatings are applied over the condenser aperture, the state of coherence at the object plane and hence the image forming properties of the system are modified. Two different types of effective source irradiance distribution functions have been assumed; in the first type the irradiance is maximum at the centre of the source and tapers off towards its edges, the reverse is true for the second type. The generalized cross transfer functions have been evaluated for various values of coherence parameter and have been applied to get the sine-wave response of the system. The image irradiance distributions and the contrast in the images of general periodic objects with rectangular and triangular wave amplitude transmission profiles have also been obtained. The irradiance distribution in the image of a straight edge object and the derivative of the edge response have also been investigated. Finally the influence of condenser size and transmission upon the two-point resolution of the system has been examined. The relative merits and demerits of the two types of the source functions have been discussed in view of these results.

The use of centrally obscured condensers is a common feature in microscopic systems. Their performance has been evaluated in terms of the sine wave response of the system. Some features of images which are characteristic of partially coherent illumination have been brought out. It has been shown that a central obscuration on the condenser of the illuminating system improves the resolving power of the system.

Performance characteristics of optical systems employing amplitude shaded apertures and operating under partially coherent illumination have been investigated. Both apodizing and super-resolving type of pupils, represented by Asakura and Sonine pupil functions respectively, have been considered. Their performance has been evaluated in terms of the spatial frequency response and the edge response of the system. The image formation by an aberration free annular aperture has also been investigated. It has been shown that its performance depends to a great extent upon the relative values of the coherence parameter ϱ and the obscuration ratio ϵ. For $\varrho > \epsilon$, the effect of obscuring the aperture is to improve the high frequency response. For $\varrho < \epsilon$ the system produces diffrimoscopic images of objects under observation.

Finally, the effect of the size of the primary source on image forming properties of microscopic systems has been discussed using the general results derived earlier. The results have been presented for a diffraction limited system employing slit apertures. An expression for the mutual coherence function at the object plane has been obtained and illustrated for some special cases. The effect of the size of the primary source upon the images of sine wave objects has been investigated.

The work presented in this thesis has been published in the form of following papers:

1. Images of periodic objects under partially coherent illumination - with A.K. Jaiswal, Optica Acta, 20 (6), 469-486 (1973).

2. Performance of apodized apertures under partially coherent illumination - with A.K. Jaiswal, Optica Acta, 20 (12), 965 - 977 (1973).

3. Influence of condenser transmission characteristics upon the performance of miscroscopic systems - with A.K. Jaiswal, Optica Acta, 21 (10), 819 - 833 (1974).

4. Sine wave response of an annular aperture under partially coherent illumination - with A.K. Jaiswal, Nouv. Rev. D' Optique appl., 5 (1974).

5. Effects of Target Contrast and Background upon Tri-bar threshold and Resolution - with A.K. Jaiswal, Applied Optics (In Press).

6. Resolution for a general two-bar target - with A.K. Jaiswal, Communicated for publication.

7. Image Evaluation by Single-bar and Single-disc analysis- with A.K. Jaiswal, communicated for publication.

C O N T E N T S