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Image Quality Versus Metric Capability

Results of a study of the Image Quality against the metric capability of mapping camera Zeiss RMK réseau indicate that certain image quality parameters may be the controlling ones over image measurement capabilities in a given area of photographic format.

ABSTRACT: *A study of the Image Quality against the metric capability of mapping camera (Zeiss RMK réseau) is reported. A laboratory experiment was designed and conducted to investigate resolution, contrast transfer and edge sharpness (acutance) against image measurement in various locations of the photographic format. Glass plate targets containing multiple contrast three bar patterns and a standard resolution target were photographed through a light source-collimator-camera system. A microanalyzer (microdensitometer combined with a precise comparator integrated with analog and digital recording capabilities) was used for the studies. Over two thousand edge measurements were made. The results indicate that, among other things, certain image quality parameters may be the controlling ones over image measurement capabilities in a given area of the photographic format. An application of this knowledge can be the derivation of a weighting system for photogrammetric observations. The user may stress the influence of particular quality factors in such weighting.*

INTRODUCTION

THE PHOTOGRAMMETRIST IS CONCERNED about the *metric capability* of the photograph and he is aware of the various methods of expressing the *quality of the image*. The fundamental curiosity remains in his mind as to the possible correlation between them.

Image quality effects on the metric capability, particularly in aerial photography, are of significant concern to photogrammetrists. The increasing interest is also involved in the innovations and improvements in the camera, the measuring equipment and techniques. Certain factors which influence the qualitative assessment of photographic images have been described and studied by various scientists in the recent past, yet there remains an increasing need to relate these factors to mensuration potentials of such photographs.

There is no universal acceptance of a single image quality factor in evaluating the performance of a photographic camera. All of the popular ones have identifiable limitations. It is the combination of image quality factors, derived from the same source, which is possibly the best solution to the problem. The research which this report describes was designed to the above possibility.

The image quality factors considered in this study are: (1) Resolution (Resolving power), (2) Contrast (Modulation Transfer) and (3) Acutance (for edge sharpness). The relationship of these image quality factors to one another and their correlation to mensuration precision are what were studied. Other image quality criteria such as granularity, etc., although worthy of investigation, could not be included because of limitations in time and resources. They are generally considered to be of insignificant influence on the metric capabilities.

For the photogrammetrist, an established relationship between measuring error and image quality factors would provide the means of "Weighting" observations in different locations of the photograph format. Such capability is not afforded to him now. Based upon experimental results, a somewhat simple weighting technique is suggested in this paper.

Laboratory Equipment and Procedure of Data Generation

Glass plate targets containing multiple contrast three bar patterns and a Military Standard Resolution target (MSRT) were photographed through a light-source collimator-camera system. The camera used was a Zeiss RMK-AR 15/23 aerial survey (Réseau) camera (owned by the OSU Department of Geodetic Science) loaded with Kodak Panatomic-X Aerial film. The laboratory arrangements permitted rotation and tilting of the camera so that the target images were placed along a diagonal and a semi-axis of the photographic format at predetermined locations. The glass plate targets and images were then scanned by using a 1 μm × 80 μm slit in a Micro-Analyzer (Mann-Data), which digitized discrete density values at one micrometer intervals along the scanning direction. Through a computer plotting program selected portions of the scanned items were presented at a graphic scale readable to less than 1 μm. The plots were then measured and analyzed to yield information on image quality parameters and effects. (See Figures 1 and 2 for the equipment.)

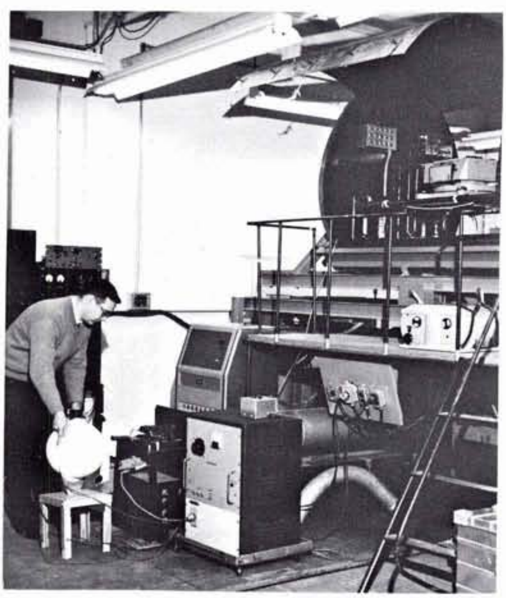

Fig. 1. Laboratory Set-up Showing Light Source, Collimator, Test Stand and Camera.

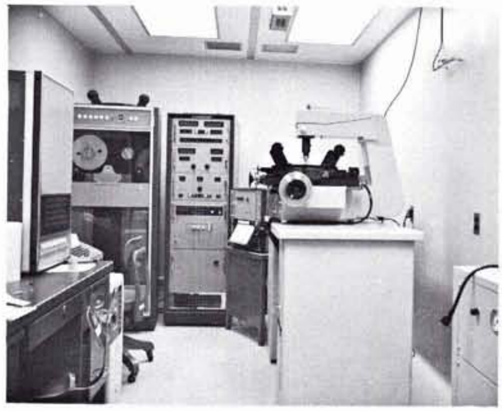

Fig. 2. Mann-Data Micro-Analyzer System Used for Data Generation.

The target was a glass plate, $4 \times 3^1/_2 \times {}^1/_{16}$ inch, coated with Kodak "High Resolution" (96-135 lines per mm) emulsion. In three quadrants were placed longline patterns of high, medium and low contrasts, whereas in the fourth quadrant was located a Military Standard Resolution Target of high contrast. The three-bar elements in all quadrants decrease in width by a factor of $2^{1/6}$. After some experimentation, the production of these targets was accomplished by using precision-made master targets and the method of contact printing (emulsion to emulsion) with variable exposure to obtain the different contrasts.

Xenon light source in a 12 inch integrator ball was used to provide the illumination. After passing through a neutral density filter and the target, the bundle of light was collimated in an 80-inch, f/10 collimator. A fixed first surface mirror reflected the rays upward into the aerial camera which was placed with vertical camera axis in a test stand. This helped simulate a vertical aerial photographic case (see Figure 1).

All exposures made over the desired réseau cross were taken with the minus blue filter B. The proper placement of the image was accomplished by tilting, rotating and translating the camera. A temperature of 74°F (~23°C) and relative humidity of 42% were recorded at the test stand each day.

The film (Kodak Panatomic −X Aerial film 3400, Ester thin base) is a panchromatic 9.5 inch film featuring high contrast, high acutance and high resolving power. This film was used in order to minimize the film effects on the image as much as possible. Kodak DK-50 chemistry was used on each strip of test film and the characteristic curve plotted

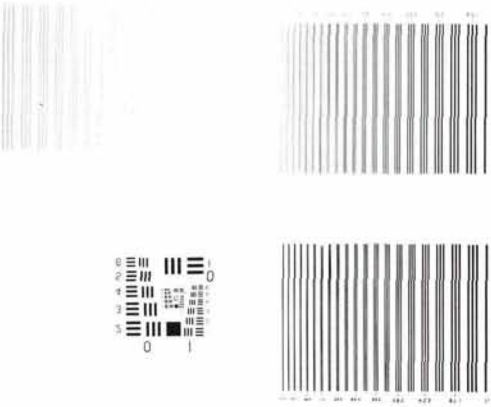

FIG. 3. Radial (R) Target.

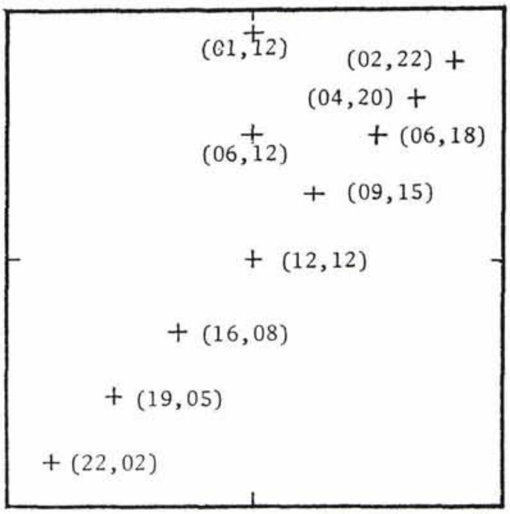

FIG. 4. Image Positions In The Photographic Format—(Not Drawn to Scale).

each time after processing. A high degree of processing control was maintained and checked with a constantly maintained γ of 1.4.

The measurements made on the Mann-Data Micro-analyzer (micro densitometer combined with a precise comparator, integrated with analog and digital recording capabilities) were recorded as an analog on a paper chart and were simultaneously digitized on magnetic tape which was computer compatible. This analog record was used not only to monitor the scanning while in progress but also to assist in selecting portions of the output for processing in the computer. The digitized record contained a discrete density value per micrometer of distance traveled across the platen and served as the principal source of all linear (scanning distance) and density measurements. Scanning programs were developed and followed to allow multiple scans across each contrast group and for averaging linear and density measurements.

With a view to keeping the scanning effort at an acceptable level and to produce a manageable amount of data, only ten exposures from each of two glass-plate targets, one in the radial direction (called R-Target, see Figure 3) and another in the tangential direction (called T-Target) were chosen. Of these exposures, three were on a semi-axis and eight were along a diagonal, each group containing a center exposure (See Figure 4).

For the sake of standardizing and comparing, the target was scaled to the image plane. Further, a 3-bar group was treated as an entity consisting of 5 quantities (viz., 5 bar-space widths) determined from 6 edge coordinate measurements. All in all, 1260 edges were involved in this study as follows:

$$6 \text{ (edges)} \times 5 \text{ (scans)} \times 7 \text{ (groups)} \times 3 \text{ (patterns)} \times 2 \text{ (plates)} = 1260.$$

The density readings were made by visual estimations on the plots. The noise level in the glass-plate target scans were generally uniform and of very low amplitude with the following typical deviation about an average value:

High Contrast:	± 0.022 density units
Med. Contrast:	± 0.007 density units
Low Contrast:	± 0.004 density units

For the images, the noise level was generally higher and for all contrasts, a range of ± 0.02 to ± 0.05 density unit deviation about a mean value was estimated. Further, since density differences were used in contrast function computation, absoluteness was not required.

The Measurement Errors

Scans of the 3-bar elements on the glass plates and their images on film were plotted by using a computer driven automatic (Calcomp) plotter. Manufacturer-claimed precision in the graph paper grid in this is ± 0.005 inch ($\sim$0.12mm). The scans on the glass plates were nearly perfect square-wave curves whereas those on the images were closer to sinusoids (see Figure 2). This indicates that edge degradation, especially in the images present a problem as to the location of the boundary between a bar and the adjacent space. This problem is comparable to what a photogrammetrist would face in making edge measurements under very high magnifi-

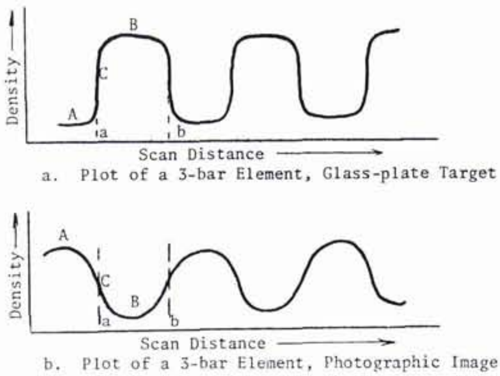

FIG. 5. Typical Plots.

cation, in the micrometer range with a high-precision measuring instrument. Typically, in such cases, the measuring mark is placed in the middle of the transition zone because a well defined boundary does not exist. A similar procedure was followed in these measurements: an average value was determined empirically for the density of the bar on one side of the edge (the boundary) and for the density of the space on the other side. Their average (density) helps determine a midpoint on the edge. A coordinate for this midpoint was read to the nearest half micrometer. Bar and space widths were readily computed from these edge coordinates.

The results of bar and space determinations for the glass-plate targets (based on 5 scans across the bar-space groups) showed that the standard deviations increased with the contrasts from low to high. The overall average of the standard deviations for the edge coordinated of glass plate scans was ± 0.7 μm. In the imagery, however, a loss of contrast in the interior of the 3 bar patterns was observed, especially as the bar/space widths decreased. As a result, a limiting resolution was reached when the 3 bars were not distinguishable any longer. For most of the situations about 1 μm precision was estimated in determining the edge coordinates from images.

The following conclusions with respect to the measuring error may be drawn:

(a) The low contrast pattern yields the widest dispersion of error in bar/space width determination. It has the most pronounced loss of measurement precision in some regions.

(b) The medium contrast pattern is better than the low contrast pattern. It has a narrow dispersion of bar/space width differences but also displays considerable weakness at 8-10 cm from the format center. Near the format center, this contrast has the best fidelity in preserving the true bar/space widths.

(c) The high contrast pattern shows the least dispersion of bar/space width differences but is generally not as faithful as the medium contrast in reproducing the target.

A plot of their average is given in Figure 10. This curve will serve as an error base line against which certain representations of the image quality factors may be compared.

RESOLUTION DETERMINATION

Resolution in the image plane was determined by means of

(1) *Visual method*, by viewing the image through the Zeiss Ultraphot II Microscope (see Fig. 6), with sharp focusing and at magnification up to 100× for each reading.

(2) *Plot method*, from the plotted (Calcomp) data.

Scanning was not done for the MSRT (Military Standard Resolution Target) in R target image. Hence a direct comparison of results obtained from the plots of all cases is not possible. However, very close agreement between the visual and plot resolution readings for the long lines (both R and T) does provide for comparison with the MSRT visual radial results.

Figure 7 displays a graph of the radial visual values. It is clear that contrast affects the resolution of a 3-bar image. It is also interesting to note that for all three contrasts, the resolution limit is practically the same at a 10-11 cm radial distance from the format

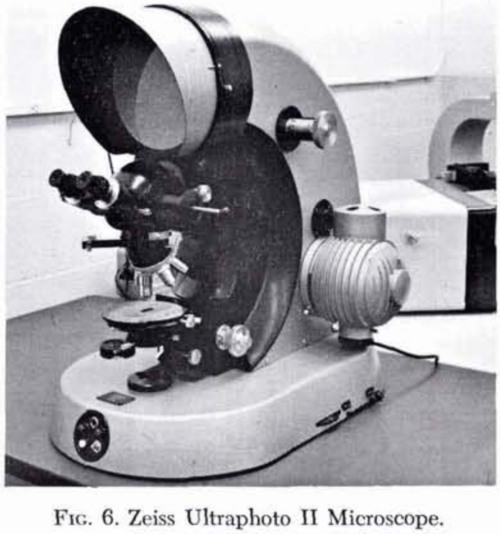

FIG. 6. Zeiss Ultraphoto II Microscope.

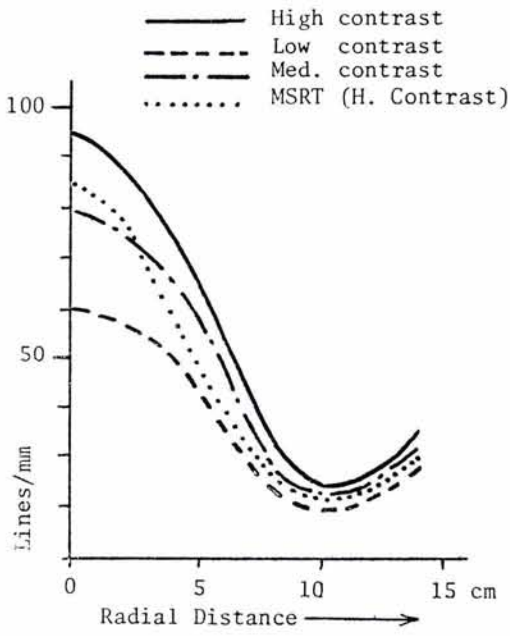

FIG. 7. Resolution, Radial Direction, Visual Method.

center. This implies that resolution loss due to contrast difference is superceded in this region by a more causative phenomenon in the image making process of the system.

Comparison of visual and plot determinations for the same patterns show a general agreement as do the limit of resolution for a given image. Reading resolutions from a plot is more convenient than peering through a microscope. One also finds that good resolution permits precise measurement and that measurement is denied as the limiting resolution is reached.

Contrast Transfer Function (CTF)

The objective of the CTF studies is to determine the ability of the photographic system to maintain a certain measure of the contrast from target (object) to image. Here the contrast (C) is defined as (D being density):

$$C = (D_{MAX} - D_{MIN})/(D_{MAX} + D_{MIN}).$$

By evaluating this quantity in both the target and image and finding the ratio of these one obtains a factor (CTF) which is a numeric indication of the transferability of contrast through the system, i.e.,

$$CTF = C_I/C_T$$

where the subscripts I and T refer to the image and target, respectively. By analogy, CTF is comparable to the Modulation Transfer Function (MTF).

Using a small computer program the values C_I, C_T, and CTF were computed for each case CTF values were obtained with respect to each format location for a given contrast and specified target (considering the spactial frequency of the bar patterns). Several observations can be made from a study of these (for further details see [8]):

a. There is an obvious correlation of CTF and contrast.

b. There is an apparent difference in CTF if measured in the radial (R) or transverse (T) direction. The T target shows highest CTF values at the format center (0.0cm) whereas the R target shows highest CTF values at the 14.1 cm location.

Edge Analysis (Acutance)

Acutance is defined by Higgins [5] as:

$$\frac{\Sigma(\Delta d/\Delta x)^2}{N(D_A - D_B)}$$

where

Δd is an increment of density
Δx is an increment of distance
N is the number of equal Δx divisions across edge
$(D_A - D_B)$ is the density difference between the toe (B) and shoulder (A) of the edge trace. (See Fig. 5b)

In real cases, acutance determination is often hampered by grain noise of emulsion. It was noticed that, generally speaking, the grain noise was minimal in the toe area (low density) but pronounced at the shoulder (high density). By using three overlaid traces (coming from multiple scanning of the edge) it was possible to empirically decide the locations of the critical points for D_A and D_B. The corresponding distance was divided by N = 10, which was held constant for all computations. The resulting Δx (and therefore Δd, depending on it) varied with the distance across the edge. A computer program was written to compute the acutance for edges of the contrast patch in the images of both targets. Figure 8 shows plots of the average acutance in the radial direction for each target. They demonstrate symmetry about the format center. The lack of similarity in the shape of the two plots may be considered in view of the fact that two independent targets (and edges), which were not simultaneously processed are being compared. Figure 9 compares resolution and

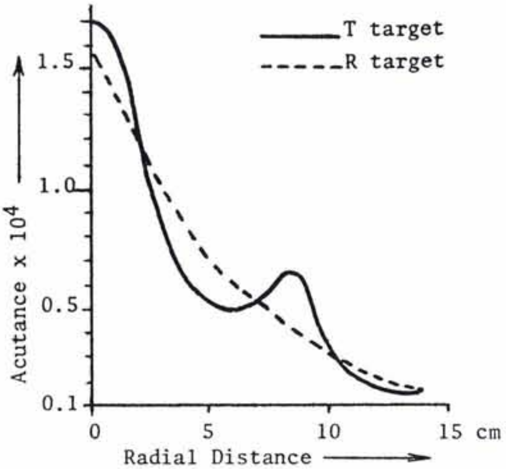

FIG. 8. Acutance—T and R Targets.

acutance of the R target in the radial direction—a typical one. Again, symmetry around the format center is noted in these cases also.

Analyses of Results

After the image quality factors of resolution, contrast transfer and acutance for various contrasts and format locations are computed and studied, it is desirable to relate these parameters to image measurements. An appropriate step would be to demonstrate the relationship of image quality and image measurement in such a way that all or selected factors could be examined in relative context.

The average absolute bar/width differences computed at each image location would

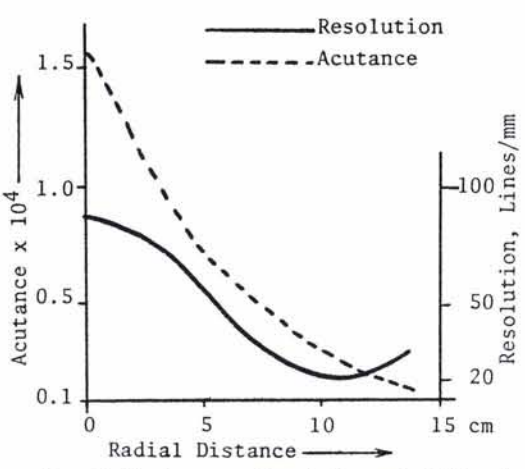

FIG. 9. Acutance vs. Resolution and R Target, Radial Direction.

indicate the magnitudes of errors in measuring. A plot of their average is essentially a mean plot—a curve (see Figure 10) which will serve as an error base line against which certain representations of the image quality must be compared. The initial difficulty arises in ascertaining the contribution to measurement error which is wholly due to image quality of lack thereof. There is also another problem of relating image quality factors which are not computed on the same basis (e.g. lines/mm in resolution, absolute unit in acutance and percentage or ratio in CTF). This dilemma is overcome by considering the *Maximum Value* (MV) concept.

To avoid the use of the units (e.g. lines/mm), regard the maximum resolution values as 100% which is the best possible resolution for the imagery throughout the format. In this case, it is found at the format center. All other resolution values are computed at percentage of the best quantity. A plot of the percentage values preserves their relativity in various locations. This procedure, called the MV technique can be easily applied to Acutance and CTF, also. The plots of such values are presented in figure 10 for one case.

It must be kept in mind, however, that the general pattern of each curve is to be considered significant but quantitative relationship should not be inferred, i.e., the MV differences at a given format location for various quality factors have no numerical equivalency. Further,

(a) All curves in Figure 10 show a similar assymetry about the format center.

(b) Resolution and Acutance are the highest where measurement errors are the smallest.

(c) CTF varies the least of all quality factors.

(d) Acutance decreases continuously from the format center outwards with the lowest values in the format corners.

(e) Resolution decreases outwards from the center but increases abruptly in the format corners.

(f) The gradual degradation of image measurement accuracy from the center out to about six centimeters is paralleled by decreases in all image quality parameters. However, past this range, from about 6 cm to the format corners, there appears to be certain interplay among the quality factors and measurement errors suggesting dominance of one factor over the others.

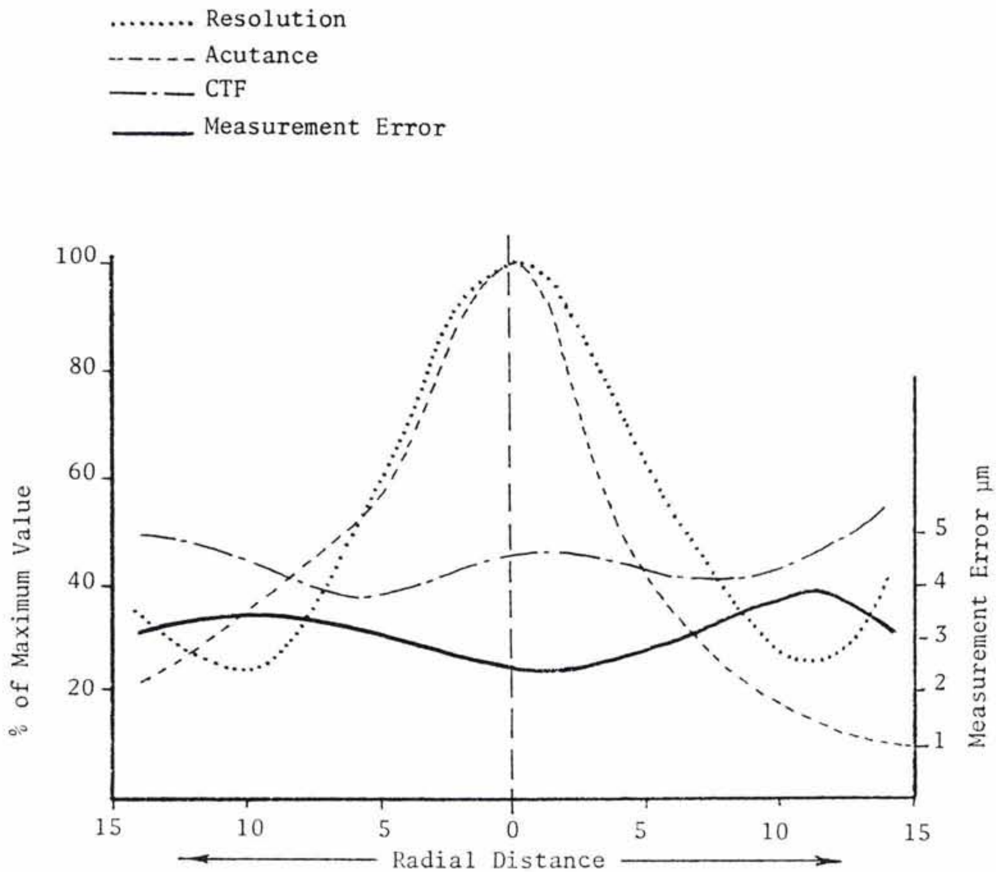

FIG. 10. Maximum Value Plots, Quality Factors vs. Measurement Errors, R Target, High Contrast.

CONCLUSIONS

Further careful analyses introduce the idea that certain image quality parameters may be the controlling ones over image measurement capability in a given area of the photograph format. It is known that Resolution and Acutance are not necessarily correlated. There is a possible correlation between CTF and Resolution under the MV concept, but the independence of Acutance is further asserted in the outer format areas. It may, therefore, be concluded that the photographic system user be concerned not only with a particular image quality factor but also with the region of dominance or weakness of that factor in influencing image measurement. An application of this theory can be the derivation of a weighting system for observations. Depending on the nature of work, the user may like to stress the influence of a particular quality factor over the others. In such cases, arbitrary constants could be introduced, e.g., for weight P,

$$P = 2.5 \times \text{(resolution value)} + 2 \times \text{(acutance value)} + 1 \times \text{(CTF value)}.$$

In practice, the use of such weighting method would presuppose an image quality determination as attempted herein. This would, however, offer rather interesting improvement to the ideas presented by Hallert (see [4]) and by Ghosh (see [3]). The mathematical model used must be effected by the physical influences.

The interested reader would find more detailed and in-depth observations made by Martucci (see [8]) in his research for the Ph.D. degree at the Ohio State University. Use of equipment, facilities and material plus helpful counsel of many personnel of the Avionics Laboratory, Wright Patterson Air Force Base, is gratefully acknowledged. Considerable financial assistance was provided by NASA, Manned Spacecraft Center, Houston, Texas.

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