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A Comparison Study of Resolving Power Targets

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A COMPARISON STUDY OF RESOLVING POWER TARGETS

by

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and

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A thesis submitted in partial fulfillment of the requirements for the degree of Bachelor of Science in the School of Photography in the College of Graphic Arts and Photography of the Rochester Institute of Technology

June, 1970

Thesis adviser: Dr. G.W. Schumann
ACKNOWLEDGMENTS

The copies of the USAF 1951 Resolution Test Pattern used in the research project were donated by W. Norman Pierce of the Optical Systems Division, Itek Corporation. The reflection copies of the Hexagon Target and the RIT Test Target were made by David C. Miller of the Graphic Arts Research Center, Rochester Institute of Technology.

The Central Intelligence Agency awarded us with a substantial financial grant. For their monetary assistance to us, and their continuing concern with higher education at R.I.T., we are indebted.
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ABSTRACT

Five high contrast (greater than 100:1) reflection test targets were investigated. The targets were: (1) USAF 1951, (2) NBS Microcopy, (3) DIN German Standard, (4) RIT, and (5) a Hexagonal test target. The targets were photographed at a reduction of 21X using a microcopying camera. Evaluation of resolving powers was made by the two research partners independently. Analysis of the resultant data involved a comparison of resolving power averages and variations for each target type. It was concluded that the five resolving power targets do not perform similarly over the region investigated. Consistent variability could not be obtained between observers with the RIT target. Different observers produced different average resolving powers with the Hexagon target. Of the remaining three targets, correlation between any two of them was poor.
INTRODUCTION

Resolving power test targets have been used in evaluating photographic images for many years. The meaningfulness and applicability of the data obtained with any given resolving power target has been in question for some time.\(^1,2,3\) Information theory and modulation transfer function approaches have helped to heighten this questioning.\(^4,5\) Very little work has been done though in comparing the actual resolving power targets presently used.\(^6\) It was the hope of the authors to compare resolving power targets now in actual use.

In extracting information from photographic images, the first task of an observer is to detect an image on the film. This has to do with the signal to noise ratio of the photographic system being used. The next task is to separate one image from another. Finally a recognition of an image is almost always required. The distinction between these three tasks is seldom made when any resolving power target is designed and used.

The objective of this research project was to determine if there is a significant difference among five high contrast reflection resolving power targets.
The comparisons of the targets were made with respect to the average resolving power generated by each target in a given photographic task, and the variations in resolving power values of each target type.
METHOD

Five high contrast (greater than 100:1) reflection test targets were investigated. The targets were:
(1) USAF 1951, (2) NBS Microcopy, (3) DIN German Standard, (4) RIT, and (5) a Hexagonal test target. The targets were photographed at a reduction of 21X using a micro-copying camera. Evaluation of resolving powers was made by both of the research partners independently. Analysis of the resultant data involved a comparison of resolving power averages and variations for each target.

Description of Targets

The USAF 1951 Resolution Test Pattern\(^7\) (see fig. 1-a) was investigated because of its wide government and industry use. The NBS Microcopy Resolution Test Chart\(^8\) (see fig. 1-b) was used because it is a standard test pattern available if the U.S.A. The NBS is a five bar test pattern (24:1 length to width ratio), while the USAF is a three bar test pattern (5:1 length to width ratio). The DIN Target (DIN Standard 19051),\(^9\) a proposed Internation Standards Organization character pattern (see fig. 1-c), was used because it is a German standard and a proposed international standard. The RIT Test Target (see fig. 1-d) was used because of its
unique design, patterns of equally recognizable alphanumeric characters.\textsuperscript{10,11} The Hexagonal Test Target was used also because of its unique design, concentric hexagonal patterns (see fig. 1-e).\textsuperscript{12}

Two of the five targets were high contrast transmission targets, and it was necessary to convert these to high contrast reflection targets. The RIT target and Hexagonal target were copied onto Kodak Ortho III Film using a process camera at RIT, and then contact printed onto Kodak Ektamatic T Paper. Detail in the reflection copies was preserved down to the resolution limit of the original transmission targets.

\textbf{Optimization of Exposure}

A Kodak Recordak Microfile Machine was used in the project to photograph the test targets. An optimization experiment was run to obtain the highest resolving powers, plus a good readable film image of one target with exposure variation. The only way to vary exposure on the Recordak Machine is by changing the operating voltage of the four illumination flood-lamps. Kodak AHU Microfilm 5460 was exposed to the USAF 1951 target at voltages of 80 to 130 volts. Processing was in Microfile Developer-Replenisher (see Appendix A). Upon resolving power evaluation, it was found that exposures of 104 to 112 volts produced the highest resolving power values, plus good readable images (see fig. 2 and 3).
The Five Targets Tested
**Factorial Experiment**

To compare the targets, a factorial experiment was run. The five targets were exposed on three film types, at four exposure levels, twice replicated. The four exposure levels used were 105, 110, 115, and 120 volts. These exposures were centered around the region of highest R.P.'s for the system as previously determined. The experimental design called for 120 film images. The initial idea behind this experiment was to draw correlation curves of the resolving power values of one target versus the resolving power values of all other targets as obtained under the various experimental conditions (i.e. 20 data points for each curve).

The three film types used were Kodak Recordak AHU Microfilm 5460, 3M Dyeback Type B Microfilm, and Kodak High Contrast Copy Film. These films were all 35mm. size, and were used in a Recordak MRD-2 Microfile Machine for photographing the targets. The illumination system of the Microfile Machine was set up following the manufacturer's instructions (see Appendix B).

The object photographed was two pages of the New York Times newspaper (Jan. 28, 1970, Sect. C, Pages 47 and 62) with one test target in the center of the object, another test target of the same type in the upper right hand corner, and a gray scale in the top center of the object (see fig. 4). This test object with the different R.P. targets in it was photographed at a 21X reduction.

Processing of the two microfilms was done together in a small stainless steel roll film processing tank. Kodak Microfile Developer-Replenisher was used (see Appendix A).
Figure 4.

gray scale

image code no.

target 

#1

target

#2
Processing of the High Contrast Copy Film was done using the manufacturer's recommended Kodak D-19 Developer, also in a small stainless steel tank (see Appendix A and fig. 5).

Due to an error in loading the processing tank, a total of 23 (out of the exposed 120) film images of the two microfilms were lost. Nonetheless, from the three films exposed and processed, 97 film images of high quality were obtained.

All film images were viewed by both research partners, resolving power values were given for the center test target appearing in each film image. The film images were viewed randomly. A Bausch and Lomb binocular microscope and illuminator were used for the R.P. evaluations. It should be noted that all images were viewed at a 100X magnification (this magnification having been first judged to be the closest in magnitude to the actual R.P. values read, as is common procedure.)

Criteria For Reading Resolving Power

The criteria for assigning a resolving power to an image of each target was set up as below. In all cases, if one group on a target was resolved, the subsequent smaller group was considered using the same resolution criteria. The smallest set resolved gave the resolving power value for that photographic image.

USAF 1951 Target

The standard for determining if a set of bars is resolved is if the three bars in the set can be detected, even distorted in shape or joined together in places, the target is resolved.
NBS Target

The same criteria as for the USAF, except instead of three bars to a set, there are five bars.

DIN Target

For a set of characters to be resolved, the reader must identify the orientation of the bars (either 0-degrees, 45-degrees, 90-degrees, or 135-degrees) correctly for seven out of eight characters in that set. In our procedure, the person not "reading" chose the eight characters (by viewing the original target) in an assumed resolved set to be identified, and the person "reading" tried to identify seven of the eight image character bar orientations.

RIT Target

The reader must name correctly all characters in one line of the target, to say those characters are resolved. On the target, initially, a bar-space distance in the character "E" in each line was measured using a filar eyepiece to get the R.P. value for that line.

Hexagon Target

The reader, using a filar eyepiece, measures the diameter of the hexagonal area in which no distinct hexagons are seen. The conversion factor 40/diameter gives the R.P. value of that image.
DATA ANALYSIS

Statistical tests were used to see if significant differences existed (at a 90% confidence level) between observers for each target. The variability associated with reading a target type was tested. This was done by a F-test. The formula used for this is $F = \frac{S_1^2}{S_2^2}$, where $S$ is a sample standard deviation of R.P. values, and $S_1 > S_2$. It was found that the variability of each observer was significantly different when using the RIT target. A statistical t-test was also run to test for a significant difference in the means of the two observers for the targets. The formulas for the t-test are:

$$s = \sqrt{n\bar{x}^2 - (\Sigma x)^2/n(n-1)}$$
$$s_p = \sqrt{(v_1s_1^2 - v_2s_2^2)/(v_1 - v_2)}$$

and

$$t = \frac{\bar{x}_1 - \bar{x}_2}{s_p\sqrt{1/n_1 + 1/n_2}}$$

where $x$ is an individual resolving power, $n$ is the number of values ($x$'s), $s$ is the sample standard deviation of $x$'s, $s_p$ is the pooled sample standard deviation of two $s$'s, and $\bar{x}$ is the average of the $x$'s.

It was found that the mean for each observer was significantly different only when using the Hexagonal target. The results of these tests are shown in Tables 1 and 2. From these two tests it was concluded that the resolving power values from the two observers could be pooled for the NBS, DIN, and USAF targets since there was no significant difference between observers for them.
Table 1

<table>
<thead>
<tr>
<th>TARGET</th>
<th>( \bar{x} )</th>
<th>( s )</th>
</tr>
</thead>
<tbody>
<tr>
<td>RIT-1</td>
<td>73.28</td>
<td>6.62</td>
</tr>
<tr>
<td>RIT-2</td>
<td>74.80</td>
<td>10.81</td>
</tr>
<tr>
<td>NBS-1</td>
<td>93.69</td>
<td>8.96</td>
</tr>
<tr>
<td>NBS-2</td>
<td>96.12</td>
<td>12.01</td>
</tr>
<tr>
<td>DIN-1</td>
<td>77.58</td>
<td>8.25</td>
</tr>
<tr>
<td>DIN-2</td>
<td>78.76</td>
<td>9.17</td>
</tr>
<tr>
<td>HEX-1</td>
<td>74.71</td>
<td>5.79</td>
</tr>
<tr>
<td>HEX-2</td>
<td>82.22</td>
<td>6.01</td>
</tr>
<tr>
<td>USAF-1</td>
<td>72.28</td>
<td>5.24</td>
</tr>
<tr>
<td>USAF-2</td>
<td>73.02</td>
<td>6.22</td>
</tr>
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</table>

Table of Averages and Standard Deviations of Each Target and Observer

Table 2

<table>
<thead>
<tr>
<th>TEST</th>
<th>F-ratio</th>
<th>F-calculated</th>
<th>sig</th>
<th>t-value</th>
<th>t-calculated</th>
<th>sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>RIT-1 vs RIT-2</td>
<td>2.67</td>
<td>2.01</td>
<td>yes</td>
<td>.59</td>
<td>1.68</td>
<td>no</td>
</tr>
<tr>
<td>NBS-1 vs NBS-2</td>
<td>1.80</td>
<td>2.40</td>
<td>no</td>
<td>.65</td>
<td>1.70</td>
<td>no</td>
</tr>
<tr>
<td>DIN-1 vs DIN-2</td>
<td>1.24</td>
<td>2.40</td>
<td>no</td>
<td>.47</td>
<td>1.68</td>
<td>no</td>
</tr>
<tr>
<td>HEX-1 vs HEX-2</td>
<td>1.08</td>
<td>2.12</td>
<td>no</td>
<td>4.13</td>
<td>1.68</td>
<td>yes</td>
</tr>
<tr>
<td>USAF-1 vs USAF-2</td>
<td>1.41</td>
<td>2.85</td>
<td>no</td>
<td>.32</td>
<td>1.71</td>
<td>no</td>
</tr>
</tbody>
</table>

Results of F-tests and t-tests for Observer Comparisons
Frequency histograms of the resolving power values were plotted for the targets to show the approximate patterns of values obtained (see figs. 6, 7, and 8). Relative cumulative frequency graphs accompany each histogram. If these relative cumulative frequency graphs approach a "S" curve, normality is indicated. It was assumed that all these graphs did approach a "S" curve for statistical purposes.

Next, statistical tests were run on the pooled resolving power values to see if significant differences existed (at a 90% confidence level) between the three remaining targets. F-tests were again run to determine if there was a significant difference in variability of the targets. T-tests were run to determine if there was a significant difference in the means of the targets.

It was found that there was significantly different variability between the NBS vs. USAF targets, and between the DIN vs. USAF targets. It was also found that there was a significant difference in means between NBS vs. DIN targets, and between NBS vs. USAF targets. (see table 3).

As proposed previously, correlation graphs of the resolving power values given by one target versus the resolving power values given by another target were considered to be useful display methods. If the plots would indicate a straight 45 degree line fit of the data points, then a one-to-one correspondence would be assumed between any two given resolving power target types.
Figure 6

Frequency Histograms

R.I.T. TARGET

1st Observer

2nd Observer

Resolving Power (Lines/mm.)
Figure 8

U.S.A.F. TARGET

Hexagon Target

1st Observer

2nd Observer

Resolution Power (lines/mm.)

R.P. Value (L/mm.)
### Table 3

<table>
<thead>
<tr>
<th>Test</th>
<th>F-calculated</th>
<th>F-value</th>
<th>sig</th>
<th>t-calculated</th>
<th>t-value</th>
<th>sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>NBS-DIN</td>
<td>1.47</td>
<td>1.74</td>
<td>no</td>
<td>5.51</td>
<td>1.67</td>
<td>yes</td>
</tr>
<tr>
<td>NBS-USAF</td>
<td>3.47</td>
<td>1.96</td>
<td>yes</td>
<td>6.64</td>
<td>1.67</td>
<td>yes</td>
</tr>
<tr>
<td>DIN-USAF</td>
<td>2.35</td>
<td>1.94</td>
<td>yes</td>
<td>2.00</td>
<td>1.67</td>
<td>yes</td>
</tr>
</tbody>
</table>

Results of F-tests and t-tests For Target Comparisons
Departures in slope or from zero intercept in the above graphs would indicate the two targets were not responding similarly in the graphical regions of such departure. These correlation graphs were plotted (see fig. 9).

The graphs indicated that there was little or no correlation between the values of any of the targets in the region investigated. For this reason the points on figure 9 were not connected by lines. To confirm the belief that there was little correlation, straight lines were fitted to the data by regression analysis, and correlation coefficients were determined for the lines (see table 4). The correlation coefficients confirmed the belief that there was very little correlation between any of the targets.

It was thought that the differences among targets and the lack of correlation might be due to a difference in image contrast. Therefore Target Image Contrast (TIC) was calculated for some sample images. This was done from microdensitometer traces of each target of equal size images. The differences found were considered to be insignificant (see table 5).
Figure 9

Correlation Graphs

N.B.S. TARGET vs. U.S.A.F.

N.B.S. TARGET vs. D.I.N.

D.I.N. TARGET vs. U.S.A.F.

Resolving Power (lines/mm)

60 70 80 90 100 110 120
### Table 4

<table>
<thead>
<tr>
<th>Correlation</th>
<th>Correlation Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>NBS-DIN</td>
<td>.37</td>
</tr>
<tr>
<td>NBS-USAF</td>
<td>.01</td>
</tr>
<tr>
<td>DIN-USAF</td>
<td>.53</td>
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</table>

Correlation Coefficients for Target Comparisons
Sample Test Image Contrasts of Four Targets

<table>
<thead>
<tr>
<th>Target</th>
<th>T.I.C.</th>
</tr>
</thead>
<tbody>
<tr>
<td>RIT</td>
<td>.56</td>
</tr>
<tr>
<td>NBS</td>
<td>.45</td>
</tr>
<tr>
<td>HEX</td>
<td>.44</td>
</tr>
<tr>
<td>USAF</td>
<td>.37</td>
</tr>
</tbody>
</table>
SUBJECTIVE OBSERVATIONS

Some pertinent comments made during the reading of the resolving power targets are noted below:

R.I.T. Target

The R.I.T. target design used in this experiment appears not to be as "sensitive" a target as has been claimed. A more continuous range of alphanumerical character sizes is, in the opinion of these authors, in order. It is felt that an equal number of characters of each size should exist in the target. Because recognition of the individual character is important, each R.P. judgement should be made on equal information content. In this experiment all the alphanumerical characters used in the R.I.T. target are not equally recognizable. The "2"'s, and the "5"'s appear easier to recognize than the "E"'s, "3"'s, and "8"'s.

Hexagon Target

The Hexagonal target image is more difficult, in practice, to focus critically on, than the other four targets. Spurious resolution shows up just by a slight defocusing of the image.

D.I.N. Target

In reading the DIN target, two methods were used to get sometimes different values. In the judgement of the orientation of the two bars on the negative, a person can look for either where the bars are, or where they are not. This did, in some
cases, result in the judgement of one particular pattern being resolved rather than another.

**N.B.S. Target**

The NBS target was the quickest target to assign a R.P. value judgement to.

**Viewing Illumination**

In some cases, a higher R.P. value could be assigned when the mirror of the light system was tilted so that a fringe of red or orange light illuminated the sample area. Whether this effect is actual or psychological, changing the hue of the light source may be important when maximum detail recognition is needed from a film image.
CONCLUSION

It is believed that the most important conclusion that can be drawn from this experiment is that the five resolving power targets tested do not perform similarly over the region investigated.

Consistent variability could not be obtained between observers with the RIT target. Different observers produced different average values with the Hexagon target.

Of the remaining three targets, correlation between any two of them was poor.
RECOMMENDATIONS

Another factorial experiment is recommended with wider exposure range, using only two targets and one film (with more replications to decrease variability). The purpose of such an experiment would be to obtain better estimates of possible target correlations.

A second recommendation would be a subjective experiment with two response variables, resolving power and readability. This would lead to a comparison and correlation of the subjective measurement readability and the objective measurement resolving power for the different targets.
FOOTNOTES


14. Rickmers & Todd, p. 73.

BIBLIOGRAPHY


5. DIN 19051, German Standard, Tests For Reprographic Use, Beuth-Vertrieb GmbH, West Berlin, Germany.


General Reference


11. MacDonald and Duncan, "Resolution As A Measure of Interpretability," Photogrammetric Engineering, 24:58.


APPENDICES
APPENDIX A

The manufacturer's recommended developer for the Kodak AHU Microfilm 5460 was Recordak Micro-File Developer Replenisher. For use, Recordak Micro-File Starting Solution is added with water to the Developer Replenisher. The proportions are: 13 1/2 fluid ounces water 2 1/2 " " Starting Solution add Developer Replenisher to make 1 gallon working solution.

Both the Kodak AHU and the 3M Dyeback microfilms were developed in this solution. Developing time was 5 minutes at 70-degrees F., followed by a 1% Acetic Acid rinse for 15 seconds, Kodak Rapid Fix (w/o hardener) for 3 minutes, wash for 10 minutes, Photo-Flo treatment for 30 seconds, and room dried. The dyeback on the 3M film was not removed during processing, and was wiped off afterwards using a sponge. This resulted in no visible degradation to the imagery.

The Kodak High Contrast Copy Film was developed in Kodak D-19 (1:0) Developer at 68-degrees F. for 5 minutes. The rest of the processing was as above.

All film was hand processed in a 35mm. double reel Kinderman stainless steel tank. The tank during processing was surrounded by a water bath at 68-degrees. Agitation during development was constant for the first 30 seconds and then was accomplished by inverting the processing tank twice every 30 seconds for the rest of the development time.
APPENDIX B

The Recordak Micro-File Machine, Model MRD-2 is equipped with 4 GE 150W/FL 120volt floodlamps for illuminating the material to be microfilmed. These lamps are approximately aimed at each corner of the copy base. The procedure for aligning the floodlamps, as given on page 23 of the Recordak Manual is:

"Place a 26¾ X 36¾ inch piece of heavy white cardboard on the base. Use a standard photoelectric light meter having a 0-75 foot-candle scale. It should be placed upward, in each of the four corners and in the center. Adjust the rheostat knob on the control unit until the center reading is 30 foot-candles. The reading at the corners should be 40 to 42 foot-candles. If necessary, adjust the lamps up, down, or sideways to obtain these readings...Test by making an exposure on white paper at 21 diameters' reduction...If the overall density of the negative varies more than 0.2, estimate the changes necessary in the corner readings; adjust the lamps to obtain these readings and make another test exposure."