An Investigation Into the Relationship Between Contrast and Resolution of a Printing System Using the RIT Contrast Resolution Test Target

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Abstract: A problem arises when different printing systems are used to print images. Different systems have considerably different contrast and resolution capabilities—while an individual printing system might have a low resolution capability, the system may have the ability to render low contrast detail. Similarly, if a printing system has a high resolution capability, it does not necessarily mean that such a system has the ability to render low contrast detail well.

The RIT Contrast Resolution Test Target has been developed to measure the relationship between contrast and resolution of a printing system. The target measures the contrast-resolution capability of the printing system in both the horizontal and vertical print direction of the printing device. A graph can be plotted to show the Contrast Sensitivity (CS) for the printing system. From this distribution, a Contrast-Resolution-Volume (CRV) can be calculated to produce a quantitative contrast-resolution measurement for an individual printing system.

The hypothesis of this paper is that the RIT Contrast Resolution Test Target can provide a method of discriminating the CRV of marking

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engines and screening methods by using analysis methods intended for use with the target. The target was printed on several printing systems. 12 observers were used to measure the target. The observers were given instruction on proper target reading, and their observations were recorded as CRV measurements. The CRV values for all colors from each system were averaged for each observer. The averaged data was entered into a two-way ANOVA test, where the two dimensions in the test were systems and observers.

The results of the ANOVA test showed that there was significant variance in the average CRV values from each system, and the hypothesis of this paper was accepted. In addition, the ANOVA test indicated that there was significant variance between the observers readings. Although each observer used a different judging criteria, it was concluded that the observers evaluated the different systems relative to one and other in almost the same sequence.

Introduction

In assessing the quality of any output system, it is important to identify the contrast limitations in addition to resolution limitations of the system. While an individual printing system might have a low resolution capability, the system may have the ability to render low contrast detail. Similarly, if a printing system has a high resolution capability, it does not necessarily mean that such a system has the ability to render low contrast detail well. Such contrast and resolution restrictions may be attributed to the capabilities of the PostScript interpreter, the screening method used by the RIP, the image transfer method of the output device, the substrate used, or a combination of these factors.

RIT has developed a target (the RIT Contrast Resolution Test Target) to measure the contrast and addressability limitations of a printing system. The target measures the contrast-resolution capability of the printing system in both the horizontal and vertical print direction. A number of observers view the printed target and indicate the point where the printing system is unable to render the test pattern. From this data, a graph can be plotted to show the Contrast Sensitivity (CS) curve of the system in both the vertical and horizontal print direction, and from the curve, a Contrast-Resolution-Volume (CRV) value can be calculated for a printing system.

The intention of this paper is to identify whether the RIT Contrast Resolution Test Target can provide a method of discriminating contrast-resolution of marking engines and screening methods by using analysis methods intended for use with the target.

Overview of the RIT Contrast Resolution Test Target

Normal graphic arts digital test targets are designed for output devices with a high spatial addressability. The writing method in these devices is binary; ink or toner can only be either on or off. Gray levels are achieved by turning some pixels on or off within a halftone cell. However, there are many output devices which cannot resolve very fine pixels; such devices are unable to generate the amount of gray levels and spatial addressability required for AM screening. However, they can still reproduce high quality images, as they are able to apply varying amounts of ink, and therefore obtain many gray levels despite their low addressability. For such devices, normal graphic arts digital test targets are unsuitable, as these targets are designed for binary systems with high spatial addressability.

The RIT Contrast Resolution Test Target can be used on low or high resolution printing systems, providing they have the ability to accept PostScript files. The targets purpose is to measure the relationship between contrast and resolution of a printing system. It is important to note that the target is measuring the capabilites of the printing system and not the printing device—a device is merely a "slave" which is controlled by the data sent from a RIP. A RIP and output device together are referred to as a printing system.

The target is shown in the Appendix. On the target, there are six contrast-resolution quadrangles; two cyan, two magenta and two black. Each quadrangle is printed once on the horizontal (x) imaging axis, and once on the vertical (y) imaging axis. The reason for this angular duplication is that many printing systems differ in contrast-resolution capabilities in the horizontal and vertical imaging directions. A yellow quadrangle has been excluded from the target, as in order to view yellow, a blue light source would be required to differentiate between the white substrate and the color. In addition, the overprint colors (red, green, blue and CMY) have been excluded from the target. The assumption is made that the hypothesis of this paper can effectively be tested solely by measuring cyan, magenta and black quadrangles.

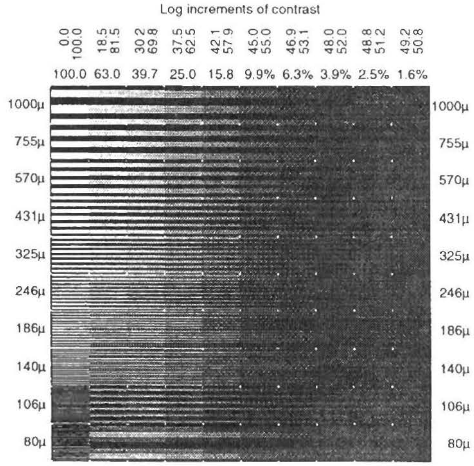


Figure 1. *The black quadrangle on the x axis from the RIT Contrast Resolution Test Target*

To illustrate the quadrangle design, the black quadrangle from the x imaging axis is shown in figure 1. Each quadrangle is constructed as a series of lines along the x axis. The x axis is divided into 10 separate "strips", these strips are separated by small black or white dots across the quadrangle. Each strip contains a series of lines with identical line width and spacing. This line width and spacing decreases logarithmically as the strips descend from top to bottom. They start off with 1000μ line and space widths, and decrease down to 80μ widths. This pre-defined line width log range can be set by editing the header in the EPS file.

In addition to the strips along the x axis, 10 strips also appear across the y axis of the target. These strips are also separated by small black or white dots across the quadrangle. The vertical strips vary in contrast from left to right. The far left strip has maximum contrast applied to the lines and spacings inside of it; 100% tonal value for the colored line, and 0% tonal value for the spacing. This decreases in logarithmic steps by strip as the strips move across the y axis of the quadrangle, from 100%/0% (a difference of 100%), to 49.2%/50.8% (a difference of 1.6%).

All strips across the y axis are centered around a single reference tint value, i.e. the total tonal value between the lines and spacing in each vertical strip remains at a constant throughout the quadrangle. By default this tint value is 50%, however, it may be required to change the reference tint value, as a 50% value will only allow a user to observe the effects of contrast-resolution in the midtone range. This reference value can be changed in the header of the EPS file.

Evaluation of the RIT Contrast Resolution Test Target

In evaluating the target, each quadrangle of the target is visually assessed. Firstly, an observer views the 100% contrast patch at a given x axis strip, i.e. an observer views the 100% contrast area within the 1000µ boundary. The observer then looks across the selected x axis strip for the area where he/she can no longer see all the lines which are present in the 100% contrast area. The lines do not have to be perfectly clear, but they must be interpreted as horizontal lines. At the last area where these lines are just visible, the contrast level for that area is recorded. For instance, at the 1000µ strip, if an observer can still distinguish all the horizonal lines that are present in the 100% patch down to 3.9%, and not lower, then 3.9% is the recorded value for the 1000µ x axis strip in that individual quadrangle. This procedure is then repeated for all remaining nine x axis strips in that quadrangle. If it is determined that the output system was unable to render the lines at a given x axis strip, then a reading is not required and the single horizontal strip is ignored.

Once all six quadrangles have been measured on a target, the recorded data can be plotted as a CS curve. By taking the two CS curves for a given color (the curves of the quadrangles which were printed both in horizontal and vertical directions), the CRV can be calculated for each individual color on a target—this calculation is explained under the Methology section in this paper. For data analysis purposes, a Microsoft Excel workbook has been developed for graphing of the CS curves and CRV calculations.

Hypotheses

H_0 : The RIT Contrast Resolution Test Target cannot provide a method of discriminating contrast-resolution-volume of marking engines and screening methods by using analysis methods intended for use with the target.

H_1 : The RIT Contrast Resolution Test Target provides a method of discriminating contrast-resolution-volume of marking engines and screening methods by using analysis methods intended for use with the target.

Methodology

The objective of this paper is to examine whether the RIT Contrast Resolution Test Target can provide a method of discriminating CRV of marking engines and screening methods. A total of eight output systems which differ in device resolution and screening methods were selected to print the target. The chosen systems were:

i) Espon Stylus Pro 5000 with Epson Stylus RIP using Epson Premium Glossy Photo Paper
ii) Iris Realist 5015 with Scitex Brisque RIP using Iris Glossy Media Paper
iii) Xerox Regal 5790 with Splash RIP using Hammermill Laser Plus Paper
iv) Kodak Approval at 28µ Velvet FM screening with Harlequin Scriptworks RIP using SWOP card base
v) Kodak Approval at 100 lpi AM with Harlequin Scriptworks RIP using SWOP card base
vi) Kodak Approval at 150 lpi AM with Harlequin Scriptworks RIP using SWOP card base
vii) Kodak Approval at 200 lpi AM with Harlequin Scriptworks RIP using SWOP card base
viii) Fuji Color Art at 200 lpi AM from Agfa Selectset 5000 imagesetter with Agfa PostScript RIP using Agfa 13" Alliance Red Sensitive Film and SWOP paper

After all the targets were printed by the selected systems, each quadrangle was cut out from the target and labelled on the back with the corresponding printing system number and the direction which the quadrangle was printed. The quadrangles were then placed in a randomized order to remove subjectivity of quadrangle presentation to the observers in the psychometric experiment. 12 observers were selected to visually evaluate the target. Prior to target evaluation, each observer was instructed in the quadrangle composition, and the process of visually recording the *x* axis strips on the quadrangles was explained. Next, each observer was presented with three "test quadrangles" to verify that the observer understood the visual evaluation process of the quadrangles. All quadrangles were presented to the observers under standardized conditions; the quadrangle was placed on a neutral gray board and viewed under a 2.8x power stand magnifier. A 60W filament bulb was used to directionally illuminate the viewing area at such an angle which did not cause shadows on the quadrangle or light reflection on the magnifier.

Once the observers had evaluated the test quadrangles and it was determined that they understood the evaluation process of the target, they were presented with each of the 48 quadrangles from the printing systems, and their measurements were recorded. For the printing systems which were unable to reproduce the narrower line widths, even at 100% contrast, the following resolutions were not recorded:

i) Espon Stylus Pro 5000 with Epson Stylus RIP at 80µ
ii) Iris Realist 5015 with Scitex Brisque RIP at 80µ, 106µ and 140µ
iii) Xerox Regal 5790 with Splash RIP at 80µ, 106µ and 140µ

From the recorded data, a CS curve was plotted for each color, on each imaging direction, of each system, for each observer. Once the CS curves for the horizontal and vertical printed directions have been plotted for a single color on a target, CRV can be calculated. To calculate volume, three-dimensions are required; resolution in the x direction, resolution in the y direction, and contrast. To calculate CRV, the units on each axis of the CS graph were taken to be the steps on the quadrangles. The area under the CS curve for the x print direction is multiplied against the corresponding curve area for the y print direction. This is illustrated in figure 2.

A problem occurs in this volume calculation method. If a quadrangle printed in one print direction can resolve a particular contrast level, and the quadrangle printed in the other print direction cannot resolve a corresponding contrast level, then a total of zero is calculated. This problem is shown in figure 2 at a contrast level of 1.6%. To account for this error, an IF statement was included in the CRV algorithm, where, in the event of multiplied units for a given contrast equal zero, then each value for the x and y print direction is squared, added together, and divided by 2.

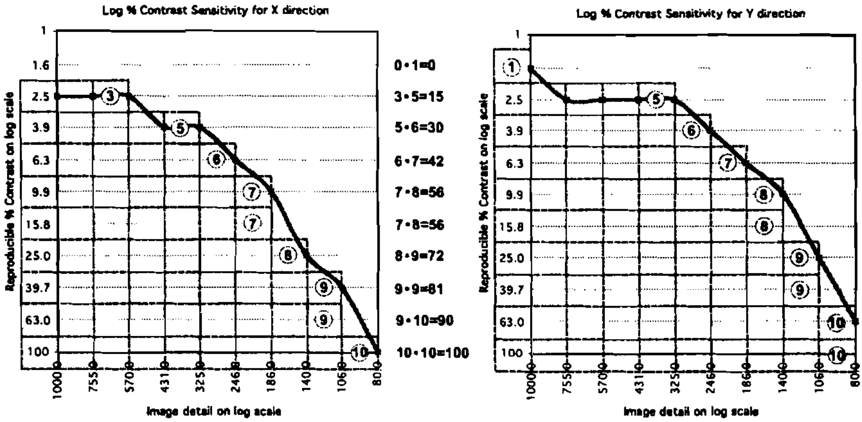


Figure 2. *Calculating Contrast-Resolution-Volume (CRV) from Contrast Sensitivity curves*

When all unit totals for each contrast level have been calculated, these totals are then added together. The total from this sum is defined as CRV. Due to the arbitary contrast and resolution parameters of the target, this volume is referred to as a *relative* volume (relative CRV), and its formula is:

$$\sum_{i1}^{i10} (\text{IF } ai \cdot bi = 0, ((ai2 + bi2)/2), \text{ ELSE } (ai \cdot bi))$$

where: i = contrast level

ai = number of 'log steps' in the x direction for i contrast level

bi = number of 'log steps' in the y direction for i contrast level

Results

In order to test the hypotheses of this paper, the CRV values from all three colors on each system were averaged for each observer. These averaged values were compiled into a table, shown in table 1.

	ACT	AGF	ALL	BSD	CCH	ECW	JCT	JPD	JSC	MEH	SXS	VKC
Epson Stylus Pro 5000 with ESR RIP	513	619	473	522	561	517	586	578	619	527	538	547
Iris Realist 5015 with Scitex Brisque RIP	370	335	252	352	379	319	350	337	350	309	335	299
Xerox 5790 with Splash RIP	384	366	243	347	372	326	357	366	378	296	352	289
Kodak Approval at 28μ FM with Harlequin RIP	487	537	392	497	511	507	520	540	535	476	511	489
Kodak Approval at 100 lpi AM with Harlequin RIP	320	322	198	245	228	216	285	243	269	170	309	186
Kodak Approval at 150 lpi AM with Harlequin RIP	461	416	326	417	404	363	472	390	435	326	435	312
Kodak Approval at 200 lpi AM with Harlequin RIP	446	452	326	453	463	442	462	425	453	404	451	400
Fuji Color Art at 200 lpi AM from Agfa film	493	541	429	493	483	483	542	515	548	425	516	428

Table 1. *Relative CRV values for each observer with each system*

This data was entered into a two-way ANOVA test, where the two dimensions in the test were systems and observers. To test whether there was any variance in the average CRV values from each system, the null and alternate hypotheses used in the ANOVA test were:

H_0: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6 = \mu_7 = \mu_8$
H_1: At least one population mean is different
(where μ_{num} = CRV mean for the system)

Using an α level of 0.01, $df_{systems} = 7$ and $df_{res.\ error} = 77$ the decision rule for this test is 'Reject H_0 and accept H_1 if the calculated F ratio is > 2.88. Otherwise, accept H_0'. The results of the ANOVA test are given in table 2. The F ratio for 'systems' is 208.74. Therefore, as the F ratio > 2.88, H_0 is rejected and H_1 is accepted. This test proves H_1 of the hypotheses for this paper that the RIT Contrast Resolution Test Target does provide a method of discriminating CRV of marking engines and screening methods.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Systems	862008.37	7	123144.05	208.74	2.32258E-47	2.88
Observers	127669.43	11	11606.31	19.67	4.02314E-18	2.49
Error	45425.29	77	589.94			
Total	1035103.09	95				

Table 2. *Two-way ANOVA without replication using an α level of 0.01.*

Furthermore, the ANOVA test shows whether each observer produced different results. The null and alternate hypothesis for this test are:

H_0: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6 = \mu_7 = \mu_8 = \mu_9 = \mu_{10} = \mu_{11} = \mu_{12}$
H_1: At least one population mean is different
(where μ_{num} = CRV mean for the observer)

Using an α level of 0.01, $df_{observers} = 11$ and $df_{res.\ error} = 77$ the decision rule for this test is 'Reject H_0 and accept H_1 if the calculated F ratio is > 2.49. Otherwise, accept H_0'. The F ratio for 'observers' is 19.67. Therefore, as the F ratio > 2.49, H_0 is rejected and H_1 is accepted. This test shows that each observer produced different results—however each observer had a different mean for all systems, and was consistent in his/her ranked judgement.

To examine the variance between the observers individual results, the CRV values for systems were sorted from the total CRV average from each observer, for each system. The CRV values were then sorted for observers from the total CRV average for all systems, for each observer. The mean, and standard deviations were calculated for each system and each observer. This data is given in table 3. From this sorted data, the means of systems versus observers were plotted to show the consistency of observers' CRV values between each system. This graph is given in figure 3.

		ALL	MEH	VKC	ECW	BSD	JPD	CCH	SXS	ACT	JCT	AGF	JSC	average	+2σ	−2σ	1 stdev
sys #5	Kodak Approval at 100 lpi AM with Harlequin RIP	198	170	186	216	245	243	226	309	320	286	322	289	249	301	197	52.288
sys #2	Iris Realist 5015 with Scitex Brisque RIP	252	309	299	319	352	337	379	335	370	350	335	350	332	367	298	34.383
sys #3	Xerox 5790 with Splash RIP	243	296	289	326	347	366	372	352	384	357	366	378	340	383	297	42.980
sys #6	Kodak Approval at 150 lpi AM with Harlequin RIP	326	326	312	363	417	390	404	435	461	472	416	435	397	450	343	63.865
sys #7	Kodak Approval at 200 lpi AM with Harlequin RIP	326	404	400	442	453	425	463	451	446	482	452	453	431	471	392	39.313
sys #8	Fuji Color Art at 200 lpi AM from Agfa film	429	425	428	483	493	515	483	516	493	542	541	548	491	536	447	44.517
sys #4	Kodak Approval at 28μ FM with Harlequin RIP	392	476	489	507	497	540	511	511	487	520	537	535	500	540	460	39.654
sys #1	Epson Stylus Pro 5000 with ESR RIP	473	527	547	517	522	578	581	534	513	586	619	619	560	594	506	44.424
	average	330	367	389	397	416	424	425	431	434	447	448	449				
	+2σ	523	595	606	612	609	651	632	609	571	658	666	680				
	−2σ	137	139	132	181	226	187	218	252	297	235	231	217				

Table 3. *Relative CRV measurements (average of CMK) for each observer on each system sorted in ascending order by total CRV average for systems and observers*

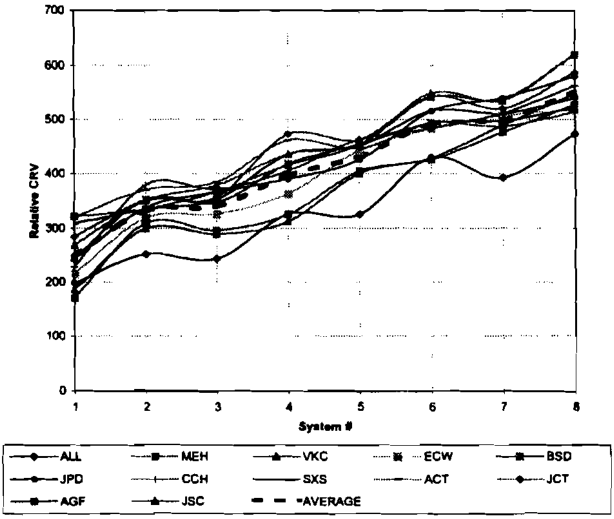


Figure 3. *Systems (sorted) versus observers' means*

From the curve distributions of each observer's data, it can be noted that observers differed in evaluating the target. However, each observer's data fell within a certain response range relative to the average of all distributions—although the judging criteria was different for all observers, each observer evaluated the different systems using a reasonably consistent assessment criteria.

		ALL	MEH	VKC	ECW	BSD	JPD	CCH	SXS	ACT	JCT	AGF	JSC
sys #5	Kodak Approval at 100 lpi AM with Harlequin RIP	16.4%	6.5%	11.2%	26.0%	46.7%	45.4%	34.4%	87.4%	91.3%	75.0%	91.7%	64.9%
sys #2	Iris Realist 5015 with Scitex Brisque RIP	0.9%	25.0%	16.6%	34.9%	72.1%	55.4%	91.2%	52.9%	86.3%	70.0%	53.3%	70.0%
sys #3	Xerox 5790 with Splash RIP	1.2%	15.6%	12.1%	37.2%	56.7%	73.1%	77.0%	61.6%	85.0%	65.5%	72.8%	81.5%
sys #8	Kodak Approval at 150 lpi AM with Harlequin RIP	9.5%	9.5%	5.9%	28.9%	65.1%	45.2%	55.8%	76.1%	88.4%	82.0%	63.9%	76.4%
sys #7	Kodak Approval at 200 lpi AM with Harlequin RIP	0.4%	24.1%	21.3%	60.7%	71.2%	43.2%	79.0%	69.1%	64.2%	76.2%	70.3%	70.9%
sys #6	Fuji Color Art at 200 lpi AM from Agfa film	8.1%	6.9%	7.6%	42.7%	51.2%	70.4%	42.5%	70.6%	61.1%	67.3%	86.7%	89.9%
sys #4	Kodak Approval at 28µ FM with Harlequin RIP	0.3%	27.3%	38.6%	57.0%	47.0%	84.0%	60.9%	60.6%	37.0%	68.9%	82.3%	61.0%
sys #1	Epson Stylus Pro 5000 with ESR RIP	4.1%	30.4%	46.9%	22.8%	26.1%	73.7%	59.6%	39.3%	20.5%	79.0%	94.1%	94.0%

Table 4. *Normal distribution percentiles for each observer on each system*

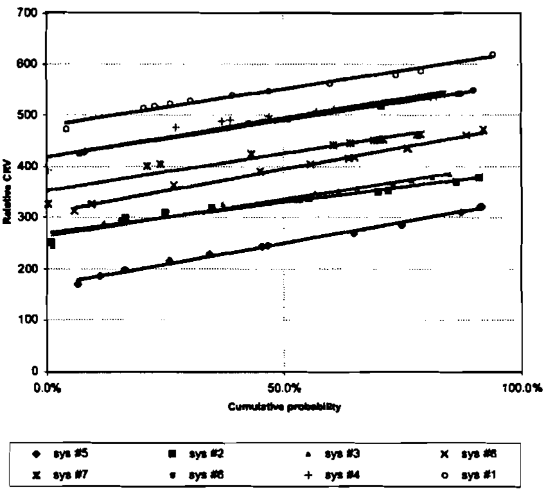


Figure 4. *Normality test of observers*

This trend was analyzed further by calculating normal distribution percentiles for each CRV value. This data is given in table 4. These percentile values were then plotted against their corresponding CRV values as a normality test. This graph is given in figure 4. Linear trendlines have been added to the graph to indicate the distribution of the observer data for each system. The graph indicates that almost all of the observers' data falls close to these lines for each system, and that all the lines fall almost parallel to one another. As the data from each observer falls almost on a straight line, it can be concluded that the data for each system is normally distributed. This is significant, as it shows that all observers had a similar standard deviation about the mean (the trendlines fall parallel to each other), and it proves that each observer used a consistent criteria to evaluate the different systems. Furthermore, as many of the trendlines are separated, it shows that the observers ranked the systems in the same relative order.

Although the target allows observers to differentiate between printing systems and rank systems in almost the same sequence, the reading of the target is subjective. Subjectivity in an observer is an unavoidable noise factor, it can be minimized through training, but never eliminated. From observers comments, it was noted that there were two main causes of subjectivity in reading the target. The first was in the target design. During the training sessions, a few observers chose contrast levels which were lower than the actual contrast addressability. The cause of this was identified that continual horizontal line widths across the contrast strips influenced the appearance of lines on adjacent contast strips. After a mask was placed over the quadrangle so that only one contrast patch could be viewed, these observers could no longer see horizontal lines in the contrast patch which he/she had previously identified as addressable. A modification of the target design could minimize or eliminate the influence of this proximity effect.

Secondly, it was noted that the screening patterns in the printed quadrangles influenced variability in observations, particularly at coarse screen frequencies. The screening patterns present in the horizontal lines proved to create confusion between observers. Many observers had difficulty in deciding which lines should be counted as resolved, and which lines should not. This reader variability is unavoidable in visual assessment of any image quality like this target, even if squares or different line shapes were used instead of horizontal lines, screening patterns would still be present.

Conclusions

The ANOVA test proved that different printing systems can be discriminated by use of the RIT Contrast Resolution Test Target. The ANOVA test also shows that the observers were using different criteria for evaluating the systems. The analysis of all the data shows that although observers appear to use different criteria, they do so in a consistent manner. Therefore, it can be concluded that an accurate evaluation of a system requires data from a number of observers.

Recommendations For Further Study

As this paper proves that the RIT Contrast Resolution Test Target provides a method of discriminating CRV of printing systems, an investigation of the target can be extended to identify different areas of the target's effectiveness. In addition, the target could be re-purposed for different uses and applications. From this paper, the recommendations for further study are:

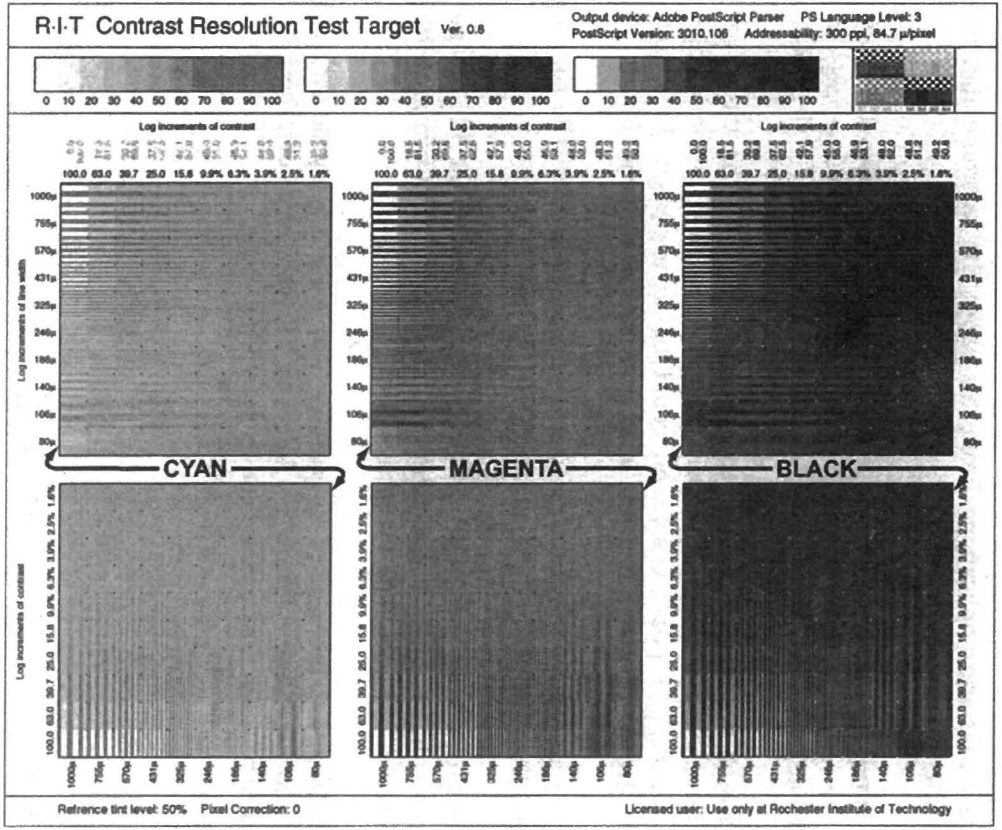
1. A similar test should be run to include images in order to verify how the results from the target correlate with the subjective impression of the images.

2. There is a possibility that adjacent horizontal patches in the target quadrangles influence one another. This could result in potential bias in evaluation. A possible solution could be to re-design the target, separating the patches with white lines, or making the patches larger.

3. There are several different approaches to calculate CRV. The simple method that was used might be improved for future work.

4. Tests could be conducted to evaluate the effect that file image compression has on CRV, by saving the target in different compression file formats, and observing the printed files.

5. The target could be used to quantify CRV for a display device, i.e. a monitor. Through assessing the target on different monitors, the CRV variance between the monitors can be recorded.



NOTE: Labels have been added to this grayscale reproduction of the target to indicate the different quadrangle colors