COMPARISON OF THE MID-FREQUENCY LINE EDGE NOISE ALGORITHMS OF JIM HAMERLY AND YIGAL GUR FOR BEST CORRELATION TO THE PSYCHOPHYSICAL DEFECT KNOWN AS RAGGEDNESS

by

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A thesis submitted in partial fullfillment of the requirements for
the degree of Bachelor of Science in the Center for Imaging
Science in the School of Graphic Arts and Photography at the Rochester
Institute of Technology

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Supervisor, Undergraduate Research

ROCHESTER INSTITUTE OF TECHNOLOGY

COLLEGE OF GRAPHIC ARTS AND PHOTOGRAPHY

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Title of Thesis COMPARISON OF THE MID-FREQUENCY LINE EDGE NOISE OF JIM HAMERLY AND YIGAL GUR FOR BEST CORRELATION TO THE PSYCHOPHYSICAL DEFECT KNOWN AS RAGGEDNESS

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Date: 15 Aug. 87

Abstract

A study was conducted to compare the mid-frequency line edge noise algorithms of Jim Hamerly and Yigal Gur. Comparisons were made to determine which algorithm correlated best with the psychophysical defect known as raggedness. Tests were conducted on "standard" observers using a series of test images with varying amounts of edge noise. A master image was produced photographically and ensuing images generated with random error using electrophotographic processes. Scanning of the images to determine output metric values was done on a Zeiss microdensitometer. It was found that with electrophotographic prints, the Hamerly algorithm has a correlation coefficient of .83. Determination of metric values for the Gur algorithm were not possible due to an error in scanning procedure. A subjective evaluation of his algorithm is included in its place.

Acknowledgements

The author wishes to first of all express thanks to Dr. Yigal Gur and Mr. Jim Hamerly for their cooperation in this thesis project.

Thanks also to Dr. Edward Granger, who as a thesis advisor provided great assistance and encouragement.

An extremely special thanks is in order for Mr. Marty Maltz and the Xerox Corporation, without whose assistance and patience this project would never been completed.

Dedication

This thesis is dedicated to the author's mother, Mrs. Clarice Huff, for her eternal love and faith in him.

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I. Introduction

"Raggedness", or "line raggedness", is a psychophysical attribute associated with the degree of breakup or lack of smoothness of the edge of a line. "Noise", or "line edge noise", is the term associated with the physical nature of that breakup.[1] Deviations from the theoretical perfect line occur because of the physical size, position, and structure of the imaging particles. These deviations indicate a need for a numerical indicator of their magnitude. This indicator would facilitate the evaluation of test images.

Mid-frequency line edge noise is a physical defect in imaging systems that causes degradation of images in the frequency range of .5 to 4 cy/mm. This range includes the 1 to 2 cy/mm frequencies in which the human eye is most sensitive.[2]

In doing perceptual analysis, the many properties of the human visual system must be considered. Also, the factors that contribute to the perception of images are important. All perceptual processes are subject to the statistical influences and the frequency selective mechanisms of the human eye.[3] The human sense of sight itself exhibits a variety of imperfections of imagery, internal noise, and other forms of image transformations.[4] The act of vision uses a convolution process so line edges are viewed as spread to some extent.[5] This fact reduces the need to generate perfect lines, because this spreading or integrating process can make an imperfect line be perceived as a perfect one. Another consideration is the perception of borders by the eye. The eye has strong overshoots at black-white borders. At these borders, the

Introduction (cont.)

blacks are blacker and the whites are whiter. This overshoot has been traced to the inhibitory mechanism in the retina.[6] Visual response from areas just outside of the white boundary is strongly repressed. Strong overshoot reduces the ability of the eye to detect small differences in brightness near the boundary. This signifigantly attenuates the visibility of noise and raises the threshold noise value in the generation of acceptable images. Aside from the eye, scale size, contrast, and viewing distance are important factors to consider when determining subjective appearances.[7]

The mid-frequency algorithm of Jim Hamerly scans down the width of a line and takes reflectance values at a specified number of points.

Figure 1. Slit placement for Hamerly algorithm

The size of the scanning slit is variable and is adjusted to the line to be measured. The slit is variable because the reflectance of the of the paper stock can cause variation in the metric values so the slit must be altered for each application. The scanning frequency is 128 points/mm. The reflectance measurements are transformed to

Introduction (cont.)

density measurements and a plot of density as a function of slit position is created.

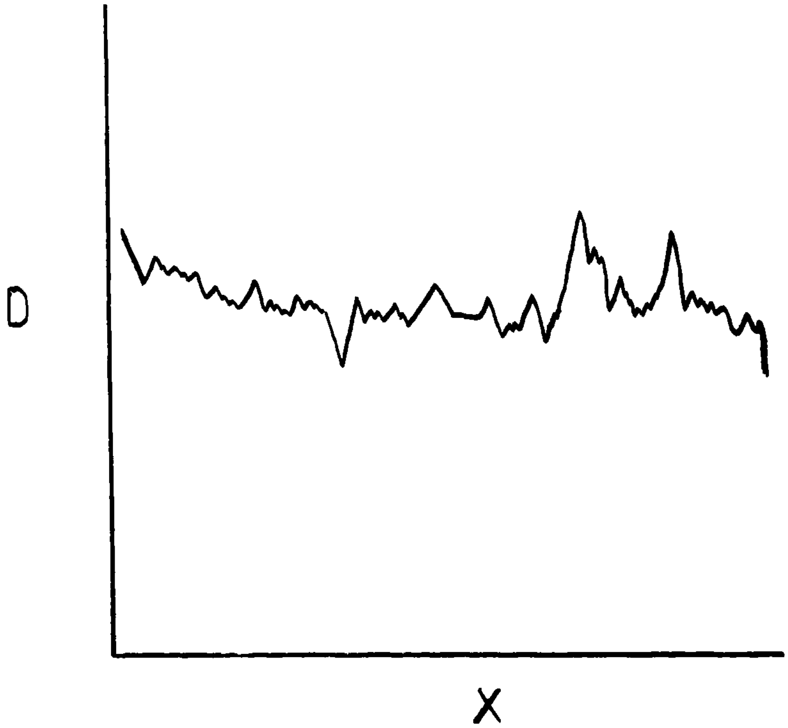


Figure 2. Density as a function of slit position plot

This data is detrended to correct for any skew in the scanning of lines. Linear trends cause error bias in the Fourier transform. The spectral amplitudes due to the linear component of the scan have been found experimentally to be larger than those due to the raggedness of the edges.[8]

The Fourier transform of this density plot, FFT(f), is the primary component of the algorithm. This density as a function of frequency plot is overlayed with a human visibility function with the following coefficients:

Introduction (cont.)

$$Vis(f) = 9.657 - 8.708f + 3.657f^2 - 0.2319f^3$$

The metric is determined by the amplitude of the Fourier transform of the density profile above the visual threshold. Studies by Hamerly have shown that the perception of raggedness is linearly related to the amplitude of the transform above threshold times a weighting function.[9] That weighting function (SMTF) is given by:

$$SMTF(f) = .02275 + 1.648f - .9053f^2 + .1898f^3 - .01793f^4 + .00061f^5$$

The line edge noise (LEN) value is determined by using a cube root of the sum of the cubes formula and is shown mathematically below:

$$LEN = \sum_{fmin}^{fmax} ((AAT(F)*SMTF(F))^3)^{1/3}$$

$$\text{where } AAT(f) = FFT(f) - Vis(f), \qquad \text{if } FFT(f) - Vis(f)$$

$$= 0, \text{ otherwise}$$

The line edge noise value is the average of the value in both directions. This algorithm is very dependent on the reflectance of the paper stock and the imaging medium.

The method of Gur for determining line edge noise employs a very different technique. Images are scanned along the edges of the lines. The resultant reflectance values are converted to density values and thresholded to create a black function. The width of the thresholded function is partitioned by the number of scan lines. The partitioned lengths of

Introduction (cont.)

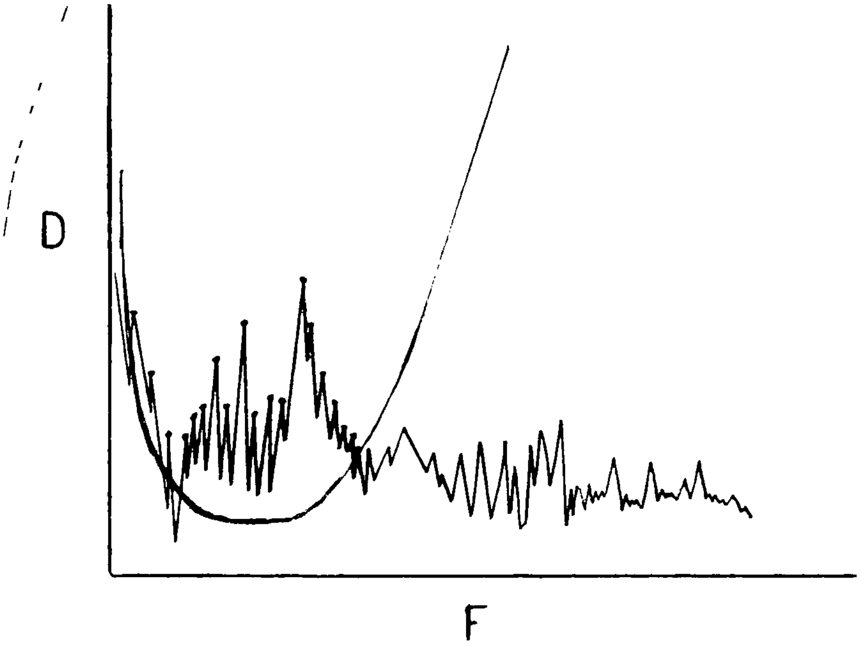


Figure 3. Weighted transform with visibility curve overlay

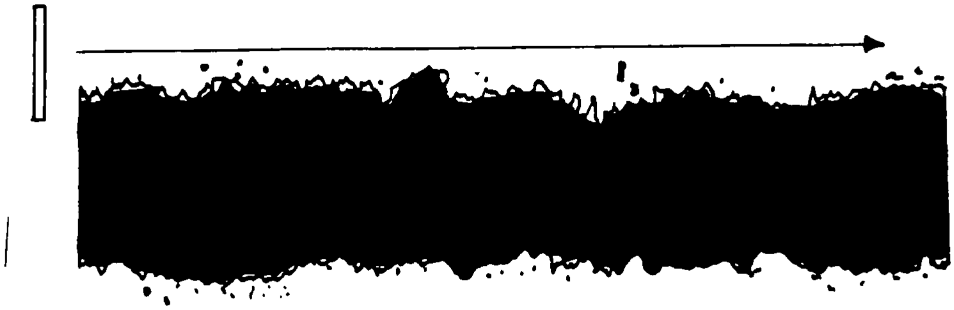


Figure 4. Gur scanning procedure

the function are then divided by the pixel size. The end result is a bit map.

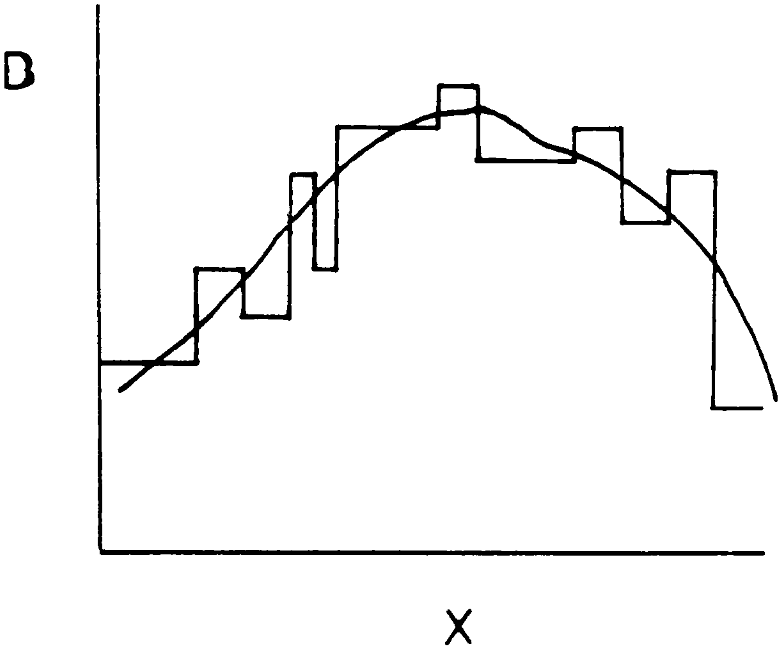


Figure 5. Bit map with smoother function overlay

A cubic spline smoother is used on this plot and produces the effective edge raggedness function. The smoother removes the low frequency component of the plot which makes up the basic shape of the character. This bit map, or edge profile, E(n), is a function of one variable, the scan number, and is proportional to a spatial dimension of the line. It is created as a difference, using the formula below:

$$E(n) = B(n) - \int_{n-1}^{n} S(x)dx$$

Here B(n) is the unsmoothed plot, and S(x) is the smoothing function. This function is Fourier transformed and a visibility curve is superimposed onto it in the same fashion as Hamerly. The values for this visibility curve are the same as earlier.

Unlike Hamerly, all of the area above threshold is totaled and then multiplied by the frequency of the first harmonic, w_1, to give the raggedness (LEN) value.[10] The formula is shown below:

$$LEN = w_1 \sum_{n} (FFT(f)_m)$$

$$\text{where } FFT(f)_m = FFT(f)_n - Vis(f), \qquad \text{if } FFT(f)_n > Vis(f)$$

$$= 0, \text{ otherwise}$$

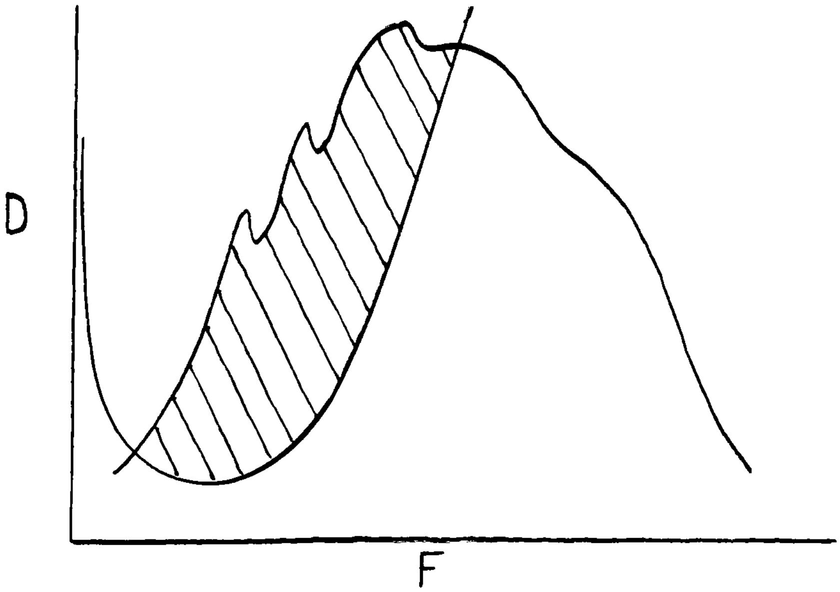


Figure 6. Gur's transformed data with visibility curve overlay

As before, the value is the average over both horizontal and vertical orientations.

As can be seen, both the algorithms employ the use of the Fourier transform. This mathematical tool converts data from the spatial domain to the frequency domain.[11] Hamerly as well as Gur determine the width of the line to be measured in some fashion but Gur takes his data and quantizes it into a specified pixel size. This fact, and the different summation techniques used in determining their raggedness values indicate that the output numbers generated will be very different.

II. Experimental

Generated original image by shooting Kalt Lithographic film rated at E.I. 25. Exposure was bracketed ± 2 stops. Lithographic film was used to achieve sharp black-white boundaries. Processing was done by hand using Kodalith developers A and B for 3 minutes. Film was stop-bathed for 30 seconds and fixed for 4 minutes. Negative was enlarged to 8x10 print on Kodak Polycontrast Rapid II RC paper. Format size was chosen to facilitate edge defect detection.

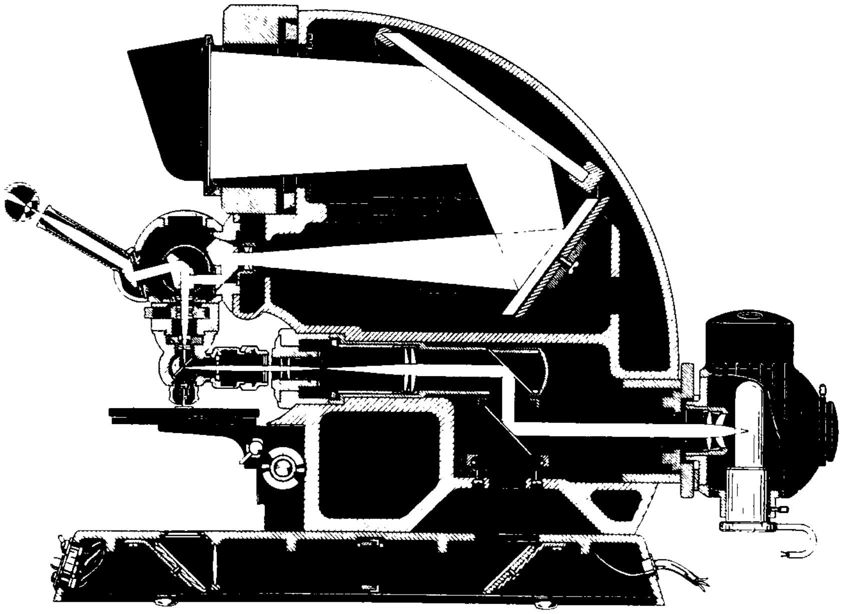
The addition of random error was accomplished by generating copies of the original on various electrophotographic systems. The systems used were the Xerox 1090 and 1045 copiers, the Canon NP350 copier, and the Canon NP9030 laser printer. Prints were copied and then copies of the copies were made to introduce more error. Some prints were generated in photo mode to introduce error caused by electronic halftoning screens. The different methods were used to try to get a wide range of edge variations. (see appendix)

The sample set of 10 prints was rated by observers in a controlled surround. Prints were viewed in a light booth equipped with 5500K bulbs to simulate daylight. The light booth was used to minimize perceptual variations due to lighting. Each print was given a code symbol and observers were asked to rate the prints using a 1 to 10 scale where 10 was best. Viewers were instructed to judge the images by the quality of the straight lines rather than the text, since only the lines were being measured.

The prints were scanned using a Zeiss Ultraphot II scanning

Expiremental (cont.)

microdensitometer with a 1550x5 micron aperture. The microdensitometer was used in reflection mode. Illumination was incandescent and the collection angle of the scanning slit was 60°. Hamerly's algorithm was used at an output frequency of .78 cy/mm. The 128 pt. sampling rate gave a Nyquist of 50 cy/mm.



Incident Illumination

Figure 8. Zeiss Ultraphot II microdensitometer

Unfortunately, the scanning technique of the Gur was not performed properly. In an effort to acquire some workable data, a scanning simulation was attempted using a Rank Xerox portable microdensitometer. Scan length was 14.4mm, with a sampling rate of 8 microns/step and an aperture size of 25x1000 microns. The sampling rate and scan length gave a Nyquist of 62.5 cy/mm. This was more than sufficient for the mid-frequency edge noise measurement. The cubic spline smoother used in the processing of the data was simply the width of the line averaged over a number of points. Subtracting the average width of the line left just the noise component of the images. It was found that the transformed data did not rise above the threshold of the visibility function. A subjective evaluation is included in the discussion section.

Statistical analysis consisted of a least-square regression line fit to the experimental data. (see appendix) The R^2 correlation coefficient was determined from this line. Perceived ratings were placed on the dependent axis to minimize the error in the data.

III. Results

The results of the experiment are shown below in tabular form.

Table 1. Experiment numerical results

Pattern #	Perceived Rating	Variance	Hamerly
1.	5.63	4.08	30.7
2.	3.99	3.17	34.4
3.	4.14	5.62	41.1
4.	4.49	8.24	35.0
5.	6.13	3.38	36.0
6.	7.39	1.08	31.7
7.	8.02	5.06	20.6
8.	7.65	6.30	19.8
9.	8.77	0.55	21.6
10.	9.07	0.22	17.2
Original	10.00	—	12.0

IV. Discussion

In a discussion of the two algorithms, the major differences between the two should be noted. The processing steps of Hamerly's algorithm differ from Gur's in everything from scanning procedure to data evaluation. The only similiarities between the two are their use of the Fourier transform and the visibility response curve. Hamerly's straddling of the line during scanning gives more output signal than Gur's scanning method, but it also gives an invalid representation of the line edge. It is an average of the two edges. This increased output signal, in combination with the weighting function used during computation, makes this algorithm more sensitive to noise detection.

With the algorithm of Yigal Gur, the input signal is not as strong as Hamerly's, because there is less of it. Also, the quantizing step of this algorithm which precedes the cubic spline smoothing, in effect provides a double smoothing, further reducing any noise present. Although the use of the total area above the visibility curve increases the output value, the sensitivity of the algorithm is still highly dependent on receiving enough signal to push any perturbations over the visibility curve.

The trade-offs here involve increased sensitivity for Hamerly, versus a truer representation of the data and ease of implementation for Gur.

V. Conclusion

The results show that Jim Hamerly's mid-frequency line edge noise algorithm correlates well with the psychophysical defect known as raggedness. An R^2 correlation coefficient of .83 was determined experimentally.

Subjective evaluation suggests that the algorithm of Yigal Gur is not as sensitive as that of Hamerly. Gur's algorithm could be very useful in a totally electronic media. Identifying and indicating the degree of misalignment in scanners by detecting the variation in pixel placement is one example. This could be a topic for future research.

VI. References

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9) Ibid., p. 18

10) Y. Gur, "Fourier Analysis of Image Raggedness", S.P.I.E.,549, pp. 22-24 (1985)

11) R.N. Bracewell, The Fourier Transform and Its Applications, McGraw-Hill, New York, 1978. p.6

VII. Appendix

The acquisition of KNOWLEDGE is based more on the ability to perceive correctly and understand than to merely intake facts. The overzealous student may sometimes do himself more harm than good by studying more than they can digest at one time.

Variations in type sizes and styles contribute to the perception of line defects.

Affective analysis must take into consideration these factors.

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Codes & Machines

⌂ ....Xerox 1045, 2nd generation

✳ ....Canon NP350

○ ....Xerox 1090, 3rd generation from Canon NP9030, 2nd generation, photo mode

⊕ ....Canon NP9030, photo mode from Xerox 1090, 2nd generation

△ ....Xerox 1045, 3rd generation

⍋ ....Xerox 1090

H ....Canon NP9030, photo mode

□ ....Xerox 1090, 2nd generation

⬡ ....Canon NP9030, 2nd generation, photo mode

\+ ....Xerox 1090, 3rd generation, copy lighter mode

THESIS DATA SHEET: K.HUFF

RAGGEDNESS RANKING

Please rank these images from best to worst, using the identification symbols in the corner of the print. Also, indicate which are acceptable and which are not by underlining the least acceptable print symbol. Thank you for your cooperation.

BEST

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WORST

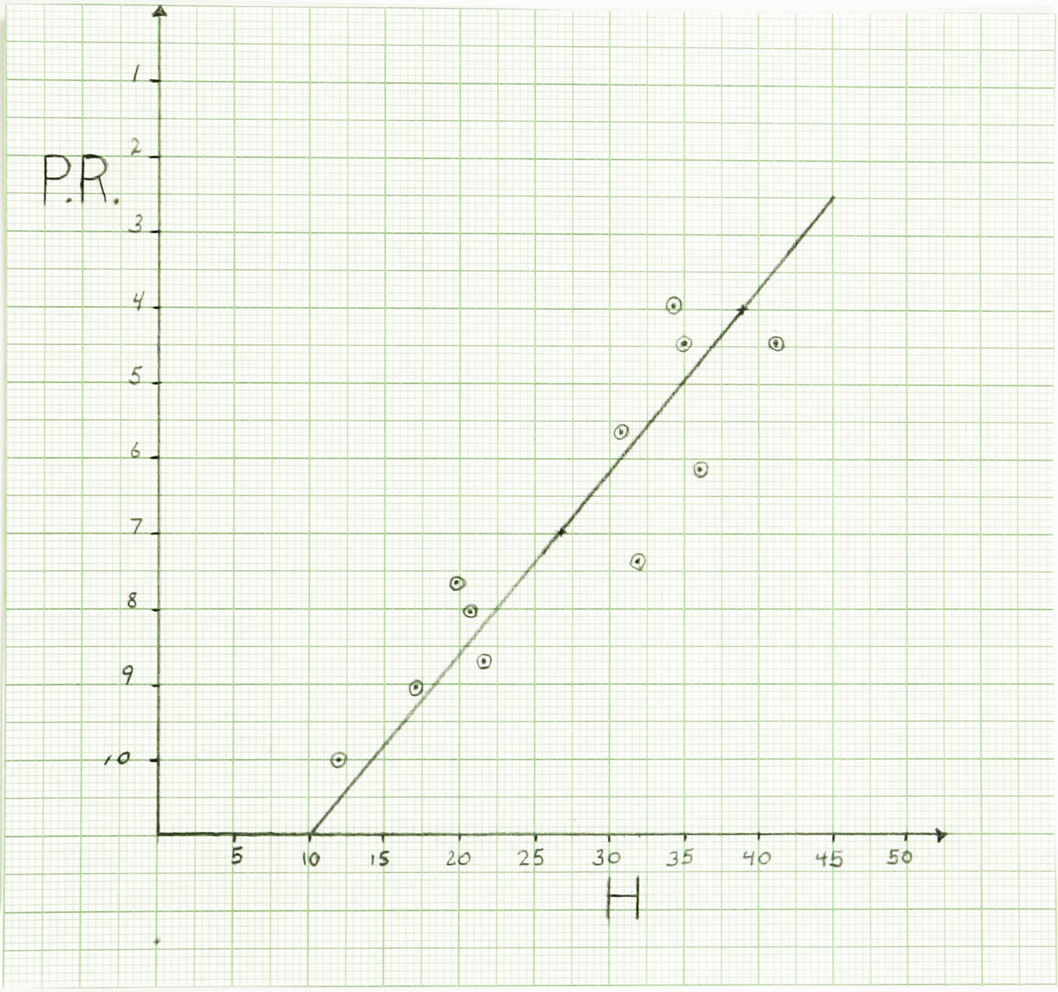

Figure 7. Perceived ratings as a function of raggedness values

VIII. Vita

The author was born and raised in New Haven, Ct., and came to the Rochester Institute of Technology in 1980. A graduate of Wilbur Cross High School, the author has been a Frederick Douglass scholar and a tutor/counselor for the Institute. He has spent the last year working as an associate engineer with the Xerox Corporation.