# Effects of Pixel Density On Softcopy Image Interpretability

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## Abstract

Softcopy viewing systems have been used to display aerial imagery for over 20 years. CRT technology has dominated the market. However, imagery viewing requirements have not been a dominant force in the marketplace. The entertainment industry, the pre-press market, and office automation have generally been responsible for technology advances.

More recently, the medical imaging community has helped to drive improvements in CRT technology. Among these improvements are ultra-high resolution monochrome monitors. In the past ten years, displays have moved from 512 by 512 pixel addressability at 50 pixels per inch (ppi) to 1200 by 1680 pixel addressability (100 ppi). In the past two years, displays with addressabilities of 2000 by 2560 (170 ppi) have come on the market. Although these five mega-pixel displays provide more data at higher resolution, there is a question as to how much of the data can be resolved by the human visual system.

To address the benefits of improved CRT resolution, 100 and 170 ppi monitors were compared at varying magnification levels (and thus effective resolutions). Trained image analysts viewed imagery on the monitors and provided National Imagery Interpretability Rating Scale (NIIRS) ratings. They also viewed Briggs targets (checkerboard patterns at varying contrast and resolution levels) and provided ratings. Results indicate that interpretability is optimized at pixel densities on the order of 70-80 ppi.

## Introduction

Over the past twenty years, CRT technology has provided displays with significant increases in the number of displayable pixels. Displays of the 1970s typically provided addressabilities of 256 to 512 pixels squared. Current displays are available with addressabilities of up to 2048 by 2560 pixels. Although some increase in the physical dimensions of displays has occurred, the more general tendency has been to increase pixel density, the number of pixels per unit dimension. Displays of the 1970s typically showed 50 pixels per inch (ppi), current displays handle up to 170 ppi.

The human eye can not resolve all of the pixels on current displays, it is thus necessary to magnify an image in order to see all of the detail present. The move from 50 to 100 ppi displays generally required 2x magnification; moving from 72-100 ppi to 170 ppi would presumably require even greater magnification.

To address this issue, a study was performed comparing a 100 ppi monitor with a 170 ppi monitor. Imagery analysts were asked to provide Briggs target ratings as well as delta-NIIRS ratings on the two monitors at different magnification levels. Results were analyzed to determine performance as a function of relative addressability (number of pixels displayed) and pixel density.

## Background

The ability of the eye to detect contrast differences varies as a function of spatial frequency. Spatial frequency is defined here as the number of cycles per degree of visual angle, where a cycle is defined as a transition from maximum to minimum to maximum luminance. Contrast discrimination peaks at a spatial frequency of about 2 cycles per degree. Figure 1 illustrates the relationship.[1] At both coarser and finer spatial frequencies, greater contrast is required for discrimination. At a typical viewing distance of 18 inches, a 50 ppi monitor is at 7.9 cy/deg. Although above the theoretical optimum frequency, very small contrast differences can still be detected. With a 100 ppi monitor at 18 inches, the frequency is 15.7 cy/deg. Here, the contrast discrimination threshold has increased by a factor of four or more.

When 100 ppi monitors were first introduced, imagery analysts complained about the quality of the monitors relative to the 50ppi monitors they had replaced. When images on the new monitors were enlarged by a factor of 2x, the complaints were eliminated. With the enlargement, the spatial frequency of the image detail on the 100 ppi monitor was about the same as on a 50 ppi monitor at 1x magnification.

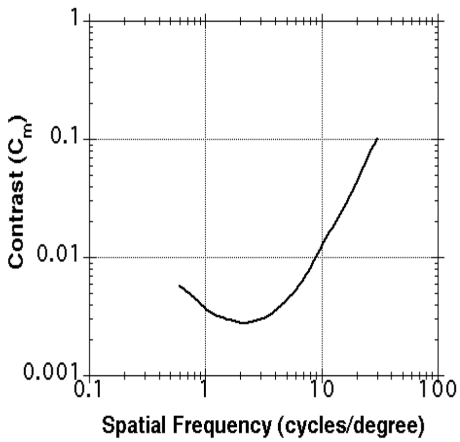


*Figure 1. Spatial frequency vs. contrast modulation.*

With an increasing number of monitors with even higher pixel densities, the question arose as to their merits relative to 100 ppi monitors. To achieve the same spatial frequency as a 100 ppi monitor at 2x magnification, images on the 170 ppi monitor would need to be enlarged by a factor of 3.4.

## Method

A sample of radar and visible imagery was displayed on a 100 ppi monitor at 2x magnification and on the 170 ppi monitor at 1x, 2x, and 4x magnification. Imagery analysts provided delta-NIIRS ratings [2] relative to the baseline (100 ppi) images. Briggs targets [3] were also rated at both 1x and 2x magnification on both monitors.

### Monitors

Two monitors were used in the study. The first had 1200 x 1600 addressability and a pixel density of 100 ppi. The monitor had 1,920,000 addressable pixels and is commonly called a two mega-pixel (2 MP) monitor. The second had an addressability of 2048 x 2560 pixels (5,242,880 pixels or 5 mega-pixels) and a pixel density of 170 ppi. The two monitors will be designated as 2 MP and 5 MP monitors in all subsequent discussion.

Other characteristics of the monitors are summarized in Table 1 as defined by NIDL.[4] Both monitors were driven by 10 bit DACs through an 8 bit frame buffer. The monitors were calibrated to a range of 0.1 to 35 fL and the NEMA/DICOM perceptual linearization look-up-table (LUT) applied.[5] The NEMA/DICOM calibration is designed to optimize contrast discrimination by varying lumiance differences between adjacent command laelves as a function of absolute luminance. It is based on a model of the human visual system by Barten[6] and was developed by Blume and Muka.[7]

**Table 1. Monitor Characteristics**

| Measure | 2 MP | 5 MP |
|---|---|---|
| Lmax | 35 fL | 35 fL |
| Lmin | 0.1 fL | 0.1fL |
| Lum. Non-unif. (max) | ND | 19% |
| Refresh Rate | 74Hz | 71Hz |
| Cm, Zone A*, Mean | 0.51 | 0.52 |
| Cm, Zone A, Min | 0.44 | 0.37 |
| Cm, Zone B, Mean | 0.48 | 0.48 |
| Cm, Zone B, Min | 0.35 | 0.33 |
| Pixel Density | 100ppi | 170ppi |

*Zone A is defined as a circle containing 40% of the addressable area.*

### Imagery

Thirty images were used in the study. Fifteen were radar images and fifteen were visible images. All of the images were chipped to 600 x 600 pixels and were then displayed at 2x magnification using bi-linear interpolation. The NEMA/DICOM perceptual linearization LUT was applied to all of the images after they had been remapped.

Histograms were generated for each image for use in subsequent analysis. The histograms were generated on the images after processing but before the perceptual linearization LUT was applied. The radar images showed highly positively skewed distributions.. The visible data tended to be normally distributed.

A sample of a Briggs target is shown in Figure 2. The numbers indicate the Briggs rating. The smallest target (one pixel squares) receives a score of 90. The C-7 (dark and light squares differ by 7 command levels) and C-3 target sets (dark and light squares differ by 3 command levels) were used. Eight targets spaced across the command level range were evaluated. For each target, the analyst identified the smallest resolvable checkerboard and then rated the "quality" of the squares on a 1 to 5 scale where 1 indicates a sharp, well formed square and 5 indicates a "blob".

### Evaluation Procedures

Twelve imagery analysts (IAs) took part in the study. Experience levels ranged from 1 year to 30 years. Each analyst began the evaluation by providing Briggs ratings on the 2 MP and 5 MP monitor at both 1X and 2X magnification. They next provided delta-NIIRS ratings on imagery displayed on the 5 MP monitor at 1x, 2x, and 4x magnification relative to the same images displayed on the 2 MP monitor at 2x magnification. At the completion of each step (magnification level) of the evaluation, each analyst completed a short questionnaire.

## Results

Data from two IAs were eliminated, one because of a monitor calibration failure and one because of unusually low Briggs scores. The average Briggs score standard deviation was 9 and rater/group correlations ranged from

0.75 to 0.91. The average delta-NIIRS standard deviation was 0.13; rater/group correlations ranged from 0.21 to 0.48. The range of delta-NIIRS was quite restricted.

**Briggs Rating Data**

Average Briggs scores (both C-3 and C-7) are shown in Figure 3. The lines shown over each bar denote the 95% confidence interval for the mean. Scores for the 2 MP monitor were significantly higher than those for the 5 MP monitor at both 1x and 2x magnification. Scores for the 2x magnification were significantly higher than those for the 1x condition.

Figure 4 shows scores for both the C-3 and C-7 target. Results are essentially the same in terms of the effects of monitor and magnification level differences. Figure 5 shows the same data plotted as a function of the log of pixel density. The scores at log values of 1.7 and 2.0 represent the 2 MP monitor, the others are from the 5 MP monitor. The correlation is very high. This is expected given the nature of the Briggs target. The value of R^2 indicates the proportion of variance in Y (Briggs score) accounted for by X (log pixel density. As the size of individual targets increase, they become easier to discriminate and scores thus increase.

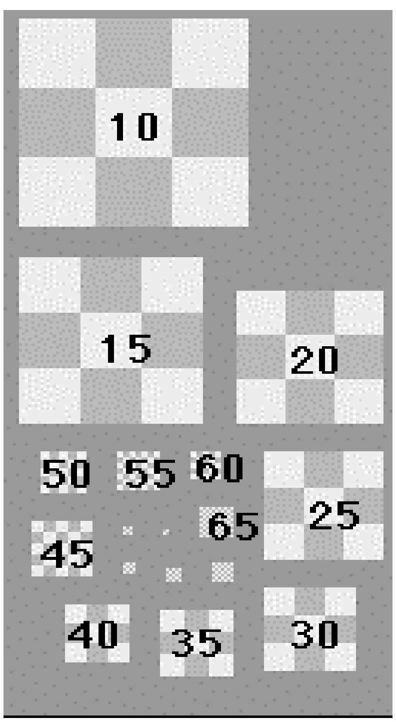


*Figure 2. Briggs target sample.*

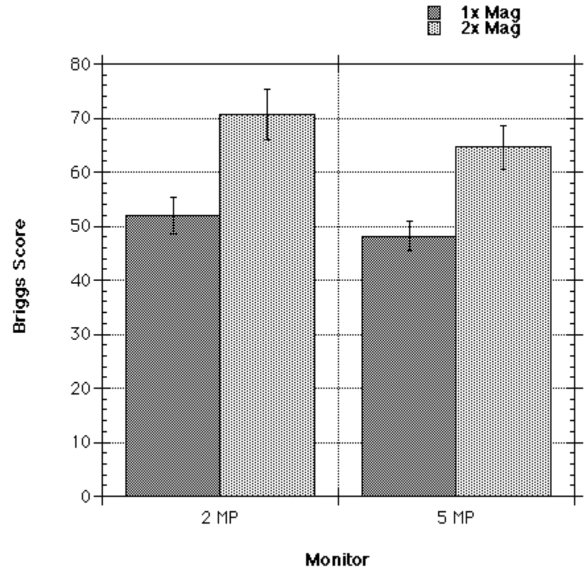


*Figure 3. Briggs scores, C-3 and C-7 target average.*

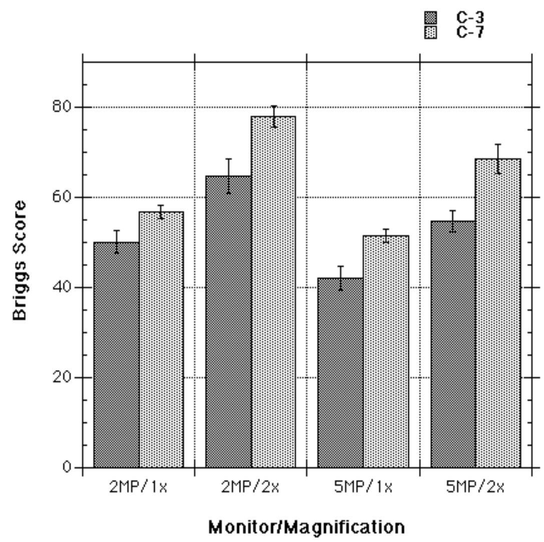


*Figure 4. Effects of magnification and target contrast level.*

**NIIRS Rating Data**

Delta-NIIRS ratings were made relative to images displayed on the 2 MP monitor at 2x magnification. Figure 6 shows ratings for the 5 MP monitor at three magnification levels. Ratings at 2x magnification are significantly higher for the 5 MP monitor. They are significantly lower for the 5 MP monitor at 1x and 4x magnification.

Figure 7 shows the effects of pixel density on delta-NIIRS ratings. The source of the individual data points is labeled. It appears that optimum performance occurs over the range of 70 to 80 ppi; additional data would be required to validate this observation.

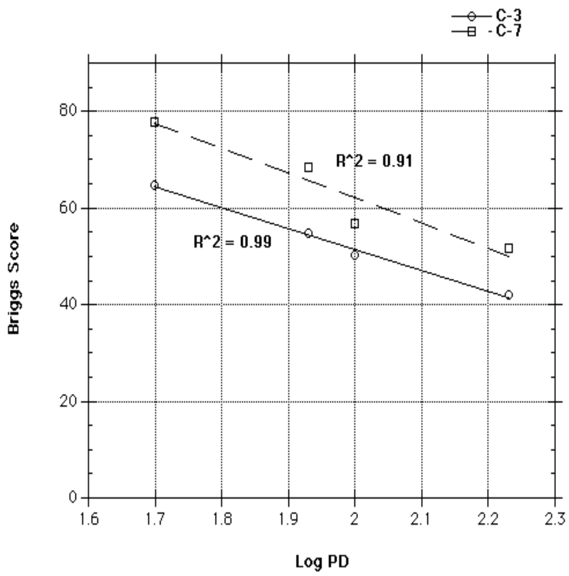


*Figure 5. Effects of pixel density on Briggs scores.*

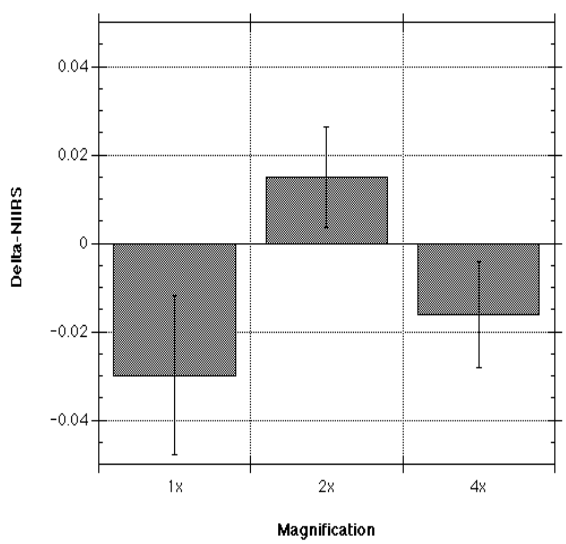


*Figure 6. Effects of magnification on delta-NIIRS*

## Subjective Assessments

After completing each step of the evaluation (change in 5 MP monitor magnification), the IAs were asked to respond to a series of questions. They were first asked to compare the monitors in terms of sharpness, lack of blockiness, contrast, lack of noise, and overall image detail. They were then asked to assess the level of magnification on each monitor.

The 5 MP monitor was preferred in terms of sharpness at both 1x and 2x magnification. At 1x magnification, however, the 2 MP monitor was preferred in terms of overall detail. In other words, the 5 MP monitor looked sharp, but based on comments, all of the detail present could not be resolved.

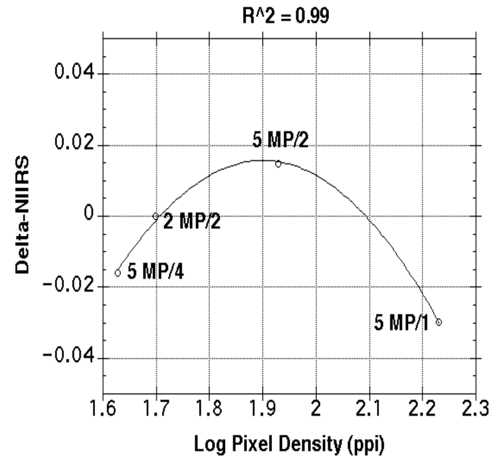


*Figure 7. Effects of pixel density.*

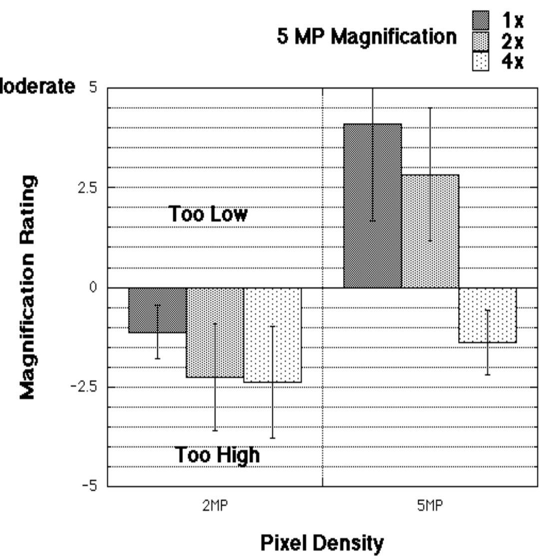


*Figure 8. Magnification preference.*

Figure 8 shows the magnification preference ratings. Ratings for the 2 MP monitor did not differ significantly from 0. In all cases, the 2 MP monitor was at 2x magnification. The 5 MP monitor was judged to have insufficient magnification at 1x and 2x and too much magnification at 4x.

## Discussion and Conclusions

The 5 and 2 MP monitors had very similar physical characteristics, differing primarily in terms of pixel density or addressability. Contrast modulation at those differing addressabilities is substantially the same. For this reason, one might expect the 5 MP monitor to provide superior performance when pixel density was matched. The Briggs data and the delta-NIIRS data only weakly supported this hypothesis. From Figure 5, the Briggs scores favored the 5 MP monitor by ~ 3 units for the C-7 target in the region of 40-50 ppi, the difference for the C-3 target was smaller. For the delta-NIIRS data (Fig6), the 5 MP monitor was favored by ~ 0.015 units.

It is concluded that the greater resolution of the 5 MP monitor was not realized in terms of NIIRS performance at 1x magnification. The 100 ppi 2 MP monitor was superior to the 170 ppi 5 MP monitor. At 2x magnification, the 5 MP monitor at 85ppi was superior to the 2 MP monitor at 50 ppi. The 2 MP monitor in turn at 50 ppi was superior to the 5 MP monitor at 42.5 ppi.

Results for both monitors suggests that optimum addressability is in the 70-80ppi range and thus at non-integer magnifications for the two monitors that were evaluated. Performance decreased at both lower and higher addressabilities. Assuming a 16 inch viewing distance, results suggest that for optimum performance, a pixel should subtend ~3 minutes of visual angle. This is smaller than predicted by the "J" curve but appears to represent a reasonable level for normal viewing of aerial imagery.

Two questions remain after this evaluation. The first is the benefit of non-integer magnification designed to achieve the target addressability of 70-80 ppi. The second is the relative benefit of a 5 MP monitor vs a 2 MP monitor at higher modulation performance than that used in the current study. In other words, is higher modulation performance or higher addressability of greater benefit?

## Acknowledgements

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## References

1. Farrell, R. and Booth, J. Design Handbook for Imagery Interpretation Equipment, Boeing Aerospace, Seattle WA, Feb. 1984
2. Leachtenauer, J. C., National Imagery Interpretability Rating Scales: Overview and Product Description, Proceedings of the ASPRS/ACSM Annual Convention and Exhibition , Vol.**1**.,pp262-272, 1996
3. Briggs, S. J., Manual Digital test target BTP#4, D180-25066-1, Boeing Aerospace Co., Seattle WA, January 1979.
4. National Information Display Laboratory (NIDL), Display Evaluation Report, Publication No. 021797-058, Princeton NJ, 12 August 1997
5. Barten, P. G. J., Physical model for the contrast sensitivity of the human eye, *Proc SPIE* **1666**, pp57-92, 1992
6. National Electrical Manufacturers Association (NEMA), Digital Imaging and Communcations in Medicine (DICOM), Part 14 ,Grayscale Display Function Standard, Supplement 28, 28 Jan 1998
7. Blume, H. and Muka, E., Presenting Medical Images on Monochrome Displays, *Information Display*, **11**, 6, (1995)