Hybrid Screening Algorithms

Bruno J. Schrappe*

Keywords: Adaptation, Graininess, Halftone, Modulation, Screening

Abstract: A computer program that creates halftone screens using both amplitude modulation (AM) and frequency modulation (FM) techniques was developed. The objective was to eliminate the characteristic graininess in flat areas found in FM screens, while still maintaining the detail rendering capabilities of frequency modulation. So as to decide where to apply each screening technique, a detail detecting program was also developed, which scans the image prior to screening. The detailed areas are screened using FM, graininess not being an issue due to the amount of detail. However, the flat or low detail areas, which are subject to graininess or objectionable patterns in FM screens, are screened using conventional AM dots. A steep transition between AM and FM screened areas is not desirable, so algorithms that blend these techniques and create "Hybrid" dots were developed and are disclosed here. The addition of noise in FM screens is evaluated and optimized, allowing for minimum perturbation, thus increasing the detail rendering capabilities of FM screens. Images generated using this technique proved to have outstanding quality, with reduced graininess and excellent detail. An alternative application for the detail detecting algorithms was found to be in determining the required amount of noise to be added to pure frequency modulation algorithms.

Detail Rendering in AM and FM Screens

Although it is true that computer-generated AM dots or contact screen dots can follow the patterns of the original image, this is only effective in very high contrast areas on the image. Early halftones created using glass screens could not reproduce as much detail as contact screens, because the size of each dot represented the average gray level of a given part of the image.

* Off7 Digital, Curitiba PR Brazil Tel: (41) 333-0707 Fax: (41) 333-0713
http://off7.com.br e-mail: bruno@off7.com.br

To illustrate the capabilities of each method, the target shown in figure 1 was specially designed. The target has areas with high contrast, such as part of the text, as well as intermediate contrast in the text as well. An object with increasing frequency of detail was added, with varying contrast.

The grayscale target was converted to a halftone using frequency modulation, shown in figure 2. Most details in the original can be seen in the halftone image.

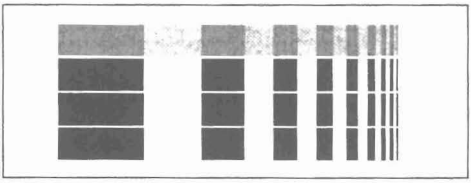

Figure 1. Target to assess detail rendering characteristics

Figure 3 shows the same grayscale target converted to a halftone using amplitude modulation. Clearly, there is less detail in areas of lower contrast. One important observation is that the conventional dots can follow the patterns of the original as long as there is high contrast, such as in the black text. In the gray text, the edges are not as well defined as they are in the frequency-modulated screen. It can also be seen that in the gray areas, the dots still can follow the pattern of the original, but with limited results. Clearly, FM screens are more efficient in determining the boundaries of lower contrast objects.

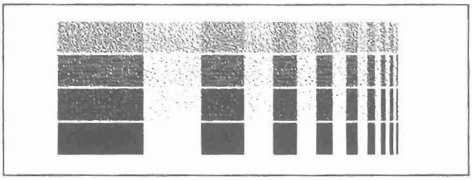

Figure 2. Frequency-modulated halftone

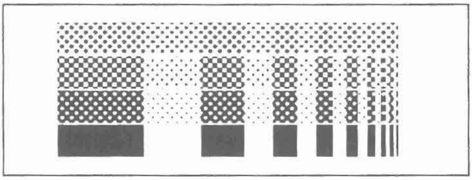

Figure 3. Amplitude-modulated halftone

Observing the rendering of the halftone steps in figure 3, it becomes evident that the detail rendering characteristics of conventional screening depend on image contrast. The high contrast areas (black or white only) were screened in the same way as in the FM screened image.

Susceptibility to Subject Moiré

Another drawback of AM screens is the appearance of interference patterns between the image and the AM screen, also called subject moiré. This problem can appear when rendering highly detailed images such as cloth or grids.

Again, to illustrate this problem, an image with a repeating pattern was created and screened using AM and FM. Figure 4 shows the grayscale image, whereas the halftones are shown in figures 5 and 6 for FM and AM screening.

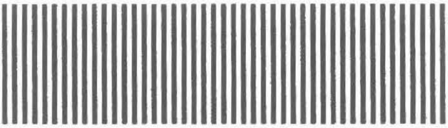

Figure 4. Target to assess subject moiré susceptibility

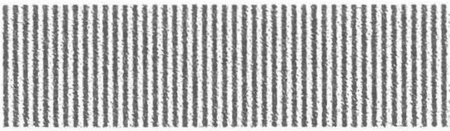

Figure 5. Frequency-modulated halftone with no interference pattern

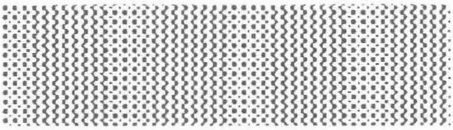

Figure 6. Amplitude-modulated halftone showing subject moiré

Interference Patterns Between Colors

Although FM screens have the potential to render more detail than conventional screens, one major drawback of using frequency modulation is the objectionable interference between dots when two or more colors are printed. Since FM dots are irregularly spaced, the interference pattern will also have an irregular distribution, resulting in white noise.

Even in conventional screens, interference patterns are unavoidable, unless dot on dot registration is achieved. However, the interference in AM screens is regularly distributed (rosette), which is more pleasant to the eyes compared to the irregular one found in FM screens, also referred to as graininess. In detailed areas, the graininess is less noticeable, since it is mixed with the detail. In flat areas, or areas without a significant amount of detail, it is more visible. In these areas, a fine halftone screen may perform better, rendering smooth tones without graininess.

Hybrid Screening Concepts

It appears to be only sensible that the best possible halftoning results demand the use of both techniques, depending on the nature of the image. If the good detail rendering characteristics of FM screening could be used with the smooth halftoning of flat areas found in AM screens, good quality images could be expected, surpassing in quality the images generated by either method alone. The author committed himself to the development of a computer program that allows these advantages to be taken. The final product is a rasterizing program that converts grayscale images to bitmapped images, where FM screening is used for detailed areas of the image and AM screening is used for areas with a low amount of detail, if any. Besides, so as not to create steep transitions between these areas, a hybrid type of screening is applied to smoothen the interface. In those intermediate areas, the FM dots progressively get more and more clustered, until AM dots are formed.

Before rasterizing, the original image is analyzed by a complementary program that detects the amount of detail surrounding each pixel. This information is then used by the program to determine the weight to be applied on FM or AM screens. Later on this report, it will also be shown that the same information allows for an optimized usage of noise, resulting in faster and more precise responses in terms of detail rendering.

The program then applies error diffusion algorithms to create the halftone. A special technique for modulating the error diffusion threshold level was developed to mix AM dots, as calculated by a threshold array, with the FM dots. This method will be further explained and discussed.

The halftone image can be seen on screen, if desired, and saved in any file format, although tiff was used throughout this project. This resulting bitmapped file can be sent to any device. It must be noted that the file will still have to pass through a RIP processor before final output, but this step will not change the structure of the dots, since they have either level zero (black) or level 255 (white).

Algorithms to Create AM Screens

In order to modulate the size of the dot according to the gray level on the original, a threshold array is used (Ulichney, 1993). Each element on the array corresponds to a square area with the size of the inverse of the addressability of the output device. In the case of 2400 dpi imagesetters, each element on the array will have a width of 1/2400 dpi = 0.42 mil per dot or 10.6 μm per dot.

To decide whether to set or not a spot, the gray level on the required area is compared to the threshold given by an element on the threshold array, which is "tiled" over the image. If the gray level is darker than the threshold, the spot is set.

The number of reproducible gray levels is given by the size of the threshold array. If more levels are desired, a larger array may be required, in which more combinations of spots are possible. Unfortunately, increasing the size of the threshold array results in larger dots, which are not desirable. There is always a trade-off between the number of reproducible gray levels and the screen ruling.

Algorithms to Create FM Screens

The concept of error diffusion is based on creating a given mean value by averaging digital or stepped values over a large vector or array. There is extensive literature on error diffusion and its applications in Graphic Arts (Allebach & Liu, 1976; Billotet-Hoffman, 1983; Roetling, 1975; Ulichney, 1994; Widmer et al, 1992).

Floyd and Steinberger (1976) proposed the following distribution of error to the neighbors:

	Δ	7
3	5	1

Where 7, 5, 3 and 1 represent fractions of the error corresponding to 16 and Δ represents the current cell.

The error for any given cell is spread as 7/16 to the neighbor cell at the right, 5/16 at the neighbor cell at the bottom, 3/16 to the cell at the bottom left and 1/16 to the cell at the bottom right.

Although this distribution of error does not eliminate all the artifacts that can appear on the halftone image, it significantly reduces it. Several other methods of dispersing the error have been proposed and tested (Ulichney, 1993), but the filter above seems to have a trade-off between simplicity and effectiveness.

Development of Hybrid Algorithms

In order to implement the rasterizing program, the C++ language on a Mac OS environment was chosen. The first stage in the development of the program was to create a working structure around which the hybrid algorithms would be developed.

After creating the required file interfaces in C++, a simple program was created, capable of performing the following steps:

- Prompt the user about the size of the file to be processed
- Dynamically allocate RAM memory for the file and related vectors
- Read the level of each pixel in the image file, saved in RAW format from Adobe Photoshop
- Process the file using error diffusion
- Output the halftone information to a file

To test the program, several files were processed, but one single grayscale image file was chosen as a reference, shown in figure 7.

Figure 8 shows the results of the first simple program written in C++, which performs halftoning functions using only error diffusion. The error was spread only to the right neighbor, in exactly the same way as described in the previous section.

Clearly, there are plenty of objectionable patterns on the image, due to the nature of the error diffusion technique. These patterns are more noticeable in flat or non-detailed areas. The main reason for these artifacts is the fact that for each line on flat areas, there will be a regularly repeating pattern of dots.

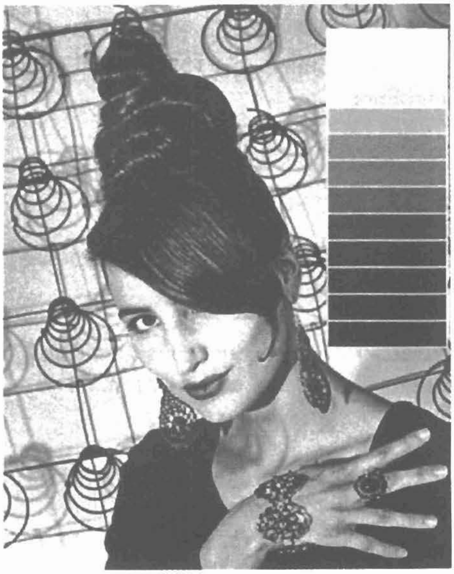

Figure 7. Reference image used in the development phase

When mixed with the patterns created on adjacent lines, they become more evident, even if there is a phase shift, as noticed in the gray steps in figure 8.

One way of representing the objectionable patterns is referring to white and blue noise. The former corresponds to a noise frequency distribution of 1/f, while blue noise has only high-frequency components. The patterns can be represented as low-frequency components of noise, which are easily noticed. In blue noise, although there is a random pattern, it has high frequency and cannot be easily noticed (Schläpfer, 1994).

One way of reducing the artifacts is changing the way the error is distributed. In order to assess the impact of this factor on image quality, different distributions were tried. The first logical step was to split the error in two parts, allowing 50% to be sent to the right neighbor and 50% to the bottom neighbor.

The resulting image can be seen in figure 9. Although patterns were reduced in some areas, there are still too many of them to allow for pleasant viewing. It suggests that this simple distribution still lacks efficiency.

Using the Floyd & Steinberg filter (Floyd & Steinberg, 1976), shown below, the artifacts were reduced, with only a few remaining in some levels of gray. The resulting image is shown in figure 10.

	Δ	7
3	5	1

Most artifacts are present in the flat areas, whereas detailed areas seem to be free of patterns. Up to this point, the algorithms were purely deterministic, since the halftone dots were solely a function of the image content, without any other factor influencing their distribution. To further eliminate the artifacts, it is necessary to add a perturbation to the process, breaking the repeatability that leads to the formation of patterns.

Figure 8. First halftone image created by the C++ rasterizing program

Figure 9. Halftone image using two-weights error distribution

Some randomness can be added to the threshold level, to which the required level plus the error is compared, or adding randomness to the weights of the error distribution. Figure 11 shows the effect of adding 50% randomness to the threshold level. Clearly, there are less artifacts, with only a few and less noticeable patterns present in the highlights.

Increasing the amount of randomness did not improve image quality from this point. Actually, a decrease in detail rendering was observed due to the excess noise added to the image. Later on, a better technique for selectively adding noise will be disclosed.

Figure 12 shows a halftone image where 20% randomness was added to the weights of the error distribution. So as not to modify the tonal values of the original, the same amount of randomness added to one weight was removed from another one (Ulichney, 1994). Some patterns can still be seen, although the image quality is good.

Increasing the randomness applied to the weights to 50% results in excess noise added to the image, degrading the detail rendering characteristics. Adding noise to the threshold level was then chosen as the technique for reducing patterns throughout this project.

Figure 10. Halftone image with four-weights error distribution (Floyd & Steinberg)

Figure 11. Halftone using Floyd & Steinberg error distribution and 50% randomness applied to the threshold level

Since AM dots will be mixed with FM in the final product, a fine ruling screen was chosen, in such a way that the dots are small enough not to interfere with the detail rendered by FM screening, but still provide a fair amount of gray levels.

Figure 12. Halftone image using 20% randomness applied to the error weights

One major simplification was done by using 1200 dpi as the maximum addressability of the imagesetter, although it may be capable of outputting films at 2400 dpi or 3600 dpi. If 1200 dpi is used, each pixel in the halftone file will be 21 μm wide, corresponding to an array of 2x2 laser spots at 2400 dpi. If 2400 dpi were used, the halftone file size would be four times larger, and the algorithms would have to calculate the four (2x2) pixels for each dot.
The drawback is that only one fourth of the possible gray levels can be achieved with the AM screens, as compared to the same screen ruling output at 2400 dpi.

The threshold array used in the program is shown in figure 13, adapted from a standard array found in the literature (Ulichney, 1994).

108	92	100	124	147	163	155	131
36	28	20	76	219	227	235	179
44	4	12	84	211	251	243	171
68	52	60	116	187	203	195	139
147	163	155	131	108	92	100	124
219	227	235	179	36	28	20	76
211	251	243	171	44	4	12	84
187	203	195	139	68	52	60	116

Figure 13. Threshold array used to generate AM screens at 45° angle

The elements were normalized to the standard 256 levels (8 bit) per color used in digital image processing. In this case, zero corresponds to black (pixels) and 255 to white (no pixels). This array can generate 33 levels of gray (32 levels plus white).

Figure 14 shows the reference image screened after the threshold array was implemented in the program. Clearly, there is more detail in the FM halftones, but the gray steps, when seen from a distance, appear to be smoother in the AM halftone.

Figure 14. Conventional halftone created with a 45° screen and 33 gray levels

Mixing Conventional and Frequency-Modulated Screens

Most images have areas with different amounts of detail. If there is a steep transition between the screening techniques, visual noise will be added to the image, which is undesirable.

A steep transition between AM and FM can be seen in figure 15. The interface is quite noticeable, suggesting a structure or pattern that is not present in the original image.

Clearly, there must be a smooth transition between those areas, otherwise image quality may be reduced. One way to achieve such a transition is to mix the shape of the dots. In other words, the FM dots must progressively cluster until the fully clustered dot pattern of AM is achieved.

This novel idea of determining the clustering pattern of FM dots basically embodies the concept on which this project was based.

After developing algorithms for both techniques, the program was modified so that AM and FM could be mixed in the same image.

Two different methods were developed and tried, explained as follows.

Probabilistic Approach to Hybrid Screening

The very first idea to mix the two screening methods was to determine, for each pixel or spot in the halftone image, if it should be set according to AM algorithms and if it should be set according to FM algorithms. Then the probability of setting the dot according to AM would be directly proportional to the amount of AM (say, from 0% to 100%) wanted in the image. The varying probability was simulated using quasi-random numbers generated by the computer. Clearly, if both AM and FM algorithms determined that a given dot should be set, the random choice was not needed. Using this technique, the image shown in figure 16 was created, corresponding to the same transition from AM to FM, but with the hybrid dots creating a diffuse interface.

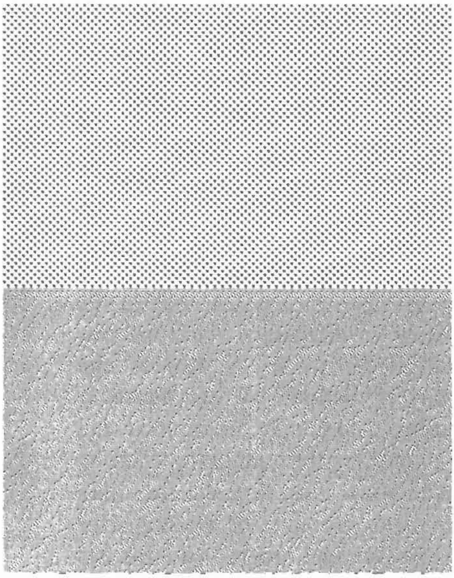

Figure 15. Halftone of a 25% tint using AM (top) and FM (bottom) with a steep transition between the two screening techniques

Although the steep transition was eliminated, there is too much white noise added to the image, as a direct result of the randomness that was added. Another way of explaining the high amount of noise is by analyzing how the FM dots are getting clustered. There is no pattern for clustering, because it happens based on probability. There are "grains" in the image, or areas with several clustered FM dots, while there are much more dispersed dots in the same gray level.

Deterministic Approach to Hybrid Screening

In order to force the FM dots to progressively cluster, the threshold level in the error diffusion algorithms was modulated according to the gray level in the original image, the AM threshold array and the amount of AM required.

The following equation illustrates the process:
Threshold Level = Mean Level + (Threshold Array Value - Gray Level) * WeightAM

Figure 17 shows the smooth transition achieved with this technique. Clearly, it is better than using the probabilistic approach, since the dots cluster uniformly for each given gray level., reducing the amount of white noise. Besides, the required computations are faster.

Technically, what is being performed is a phase shift in the error diffusion algorithms, allowing them to follow the pattern defined by the threshold array. Although the method and algorithms for combining AM and FM were developed for this project, the idea of mixing error diffusion and ordered patterns has been suggested and found in the literature (Billotet-Hoffman & Bryngdahl, 1983).

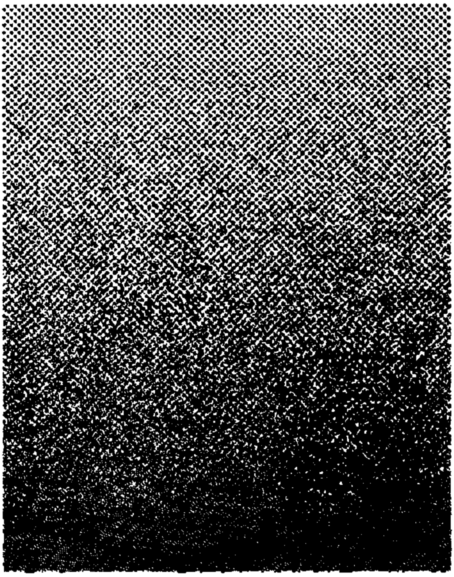

Figure 16. Halftone of a 25% tint using a probabilistic approach to hybrid screening

Detail Detecting Algorithms

As suggested by Prof. Stephen Viggiano (RIT), techniques similar to unsharp masking were applied in order to detect the amount of detail in the images. In an analogy to optical systems, consider an image is scanned with a regular aperture and a larger aperture. The larger aperture will filter out the high frequency information on the image, which will be gathered by the small aperture. If the signal from the larger aperture is subtracted from the small aperture signal, enhancements or "overshoots" will occur at high frequencies, due

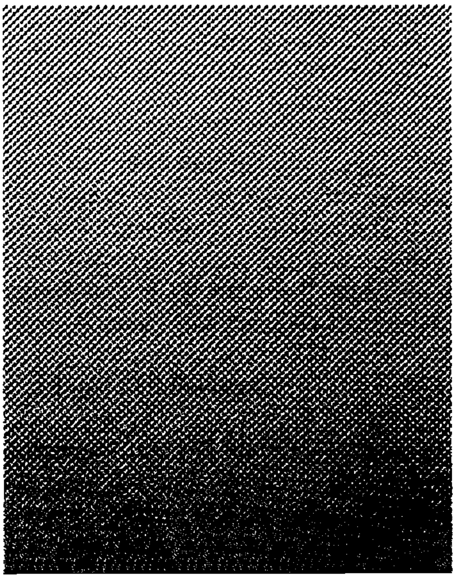

Figure 17. Halftone of a 25% tint using a deterministic approach to hybrid screening

to the different signals from the two apertures. These enhancements increase the detail contrast, making the resulting image look sharper. On the other hand, if a sharpened image is subtracted from the original, whatever is left will be due to detail enhancement, thus revealing the amount of detail in the original.

In order to test the applicability of this method, the reference image was sharpened in Photoshop, and subtracted from the original. So as to improve the smoothness of the transitions between AM and FM, a Gaussian blur filter was applied to the image, and the results are shown in figure 18. The more detail in the original, the brighter the image. Dark areas represent absence of detail.

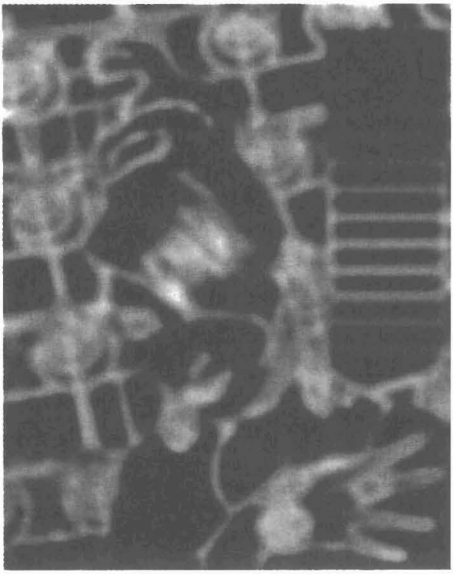

Figure 18. Detail mask created in Adobe Photoshop

The Hybrid algorithms were modified so that the detail file is read prior to screening, and the weight to be assigned to AM is now dependent on the gray level (or detail) in the detail mask file.

Figure 19 shows the first image screened using these algorithms. It can be seen that detailed areas, such as the model's mouth, eyes and jewelry were screened using mostly dispersed dots, or FM, and the dots progressively cluster when detail is reduced, such as in the model's neck or in the gray steps.

Figure 19. First image using detail-sensitive hybrid algorithms

The first implemented C++ version of detail detecting algorithms used the same approach described in the previous section, although a few modifications were necessary to improve the quality of the error detection. The unsharp masking technique works well if edges are to be detected. However, to detect more subtle detail, a method based on the first derivative of the average level of neighbor pixels was also developed and employed. The result is shown in figure 20.

An algorithm for blurring the detail mask image was also developed and implemented in the program after the detection phase. To blur an image, the gray level of each pixel is simply recalculated as the average level of its neighbors, with a decreasing weight as the distance from the neighbor pixels increase. To increase the blurring speed, a small array of neighbors was used, in multiple iterations.

Figure 20. Detail detected using improved algorithms

While the image in figure 20 shows the results after only one blur iteration, figure 21 shows the effect of using 9 blur iterations. The detail image has lower contrast, allowing for smoother transitions between AM and FM. This was determined to be an optimum parameter, above which the image becomes too smooth and the transitions between AM and FM become too large, thus noticeable.

Figure 22 represents the first image entirely processed by the developed algorithms, including the detail detecting function. There are no noticeable interfaces between AM and FM dots, and the flat areas are uniformly rendered by clustered dots, while detailed areas are efficiently rendered using dispersed dots.

Fine Tuning the Hybrid Algorithms

After developing the working Hybrid Screening prototype, a high-resolution Hybrid image was generated on film, using the Agfa SelectSet 5000 imagesetter at the Rochester Institute of Technology and copied onto photographic paper. The same image was screened using Agfa's CristalRaster at 2400 dpi.

The flat areas such as the gray steps and the background are rendered without the graininess that can be seen on the CristalRaster image. Besides, the exceptional detail rendering characteristics of FM screening are maintained. This is easily seen if the image is compared to the conventionally screened image.

Fully clustered AM dots were not used in this image. In fact, the algorithms were set up in such a way that the FM dots are partially clustered in low detail areas, and fully dispersed in high detail areas. The main reason behind this approach is the limited number of different sizes of fully clustered dots. In conventional screens, this would pose a limitation on the number of reproducible gray levels. Since the dots are calculated by error diffusion in this program, there is no such limitation. However, there are still some artifacts noticeable in the grayscale if fully clustered AM dots are employed.

One major advantage revealed by the Hybrid Algorithms is that much less noise can be added to the image, as compared to traditional FM screens. Adding perturbations can eliminate patterns in low detail areas of the image. In detailed areas, there is no formation of patterns since randomness is already supplied by the image.

Figure 21. Detail mask after nine blur iterations

Figure 22. First image entirely processed using the C++ algorithms

On the other hand, noise is not required in AM screens due to their ordered nature. In the case of hybrid algorithms, there should be no need for noise in low detail areas, since they are screened conventionally. Besides, there should be no need for noise in highly detailed areas, since no patterns are formed.

Analysis of these two screening techniques resulted in the following conclusions:

- The low detail areas are subject to some patterns since semi-clustered dots are being used, still showing some dispersed dot characteristics that can lead to objectionable patterns.
- The error diffusion technique shows a slow response time when the required gray level is at either one of the extremes (highlights or shadows), and the threshold level is set at the midtone level.

To correct for these phenomena, two series of experiments were performed. One of them indicated the minimum amount of noise that should be added to the image for each gray level, using FM screening, to improve the response time. The other one indicated the minimum amount of noise needed to eliminate patterns for different degrees of dot clustering.

A mathematical equation was derived in order to model the required noise distribution. Figure 23 shows the chart with the modeled noise distribution.

During late stages of development, a few modifications were added to the noise equation, further improving image quality. The final equation used in the algorithms also slightly depends on the detail level and has a correction for the chosen degree of dot clustering.

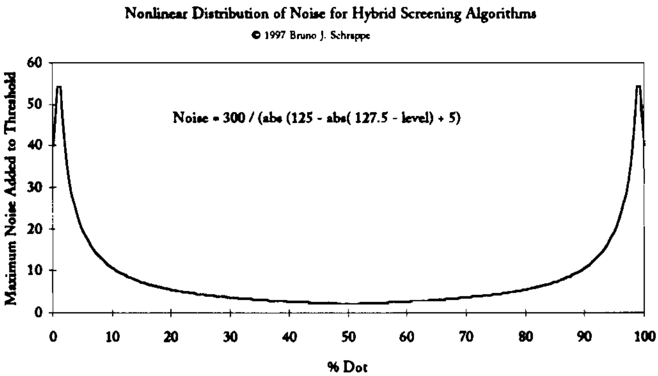

Figure 23. Nonlinear noise distribution used in the Hybrid Screening algorithms

Variations in the Detail Detecting Algorithms

Several different algorithms were tried in order to improve detail detection. Since two different techniques for sensing detail were applied (unsharp masking and first derivative), two degrees of freedom were present, and had to be tuned.
The testing phase indicated the need for a detail threshold, under which no detail was considered to be present in the image. This threshold was implemented in the algorithms.

A few images with varying parameters created during the testing phase were compared to conventional AM screening and two commercial FM screening products, Agfa CristalRaster and UGRA Velvet Screening.

The quality factors that were being analyzed were the smoothness of the transition between AM and FM, the dot patterns, the rendering of detail and obviously, the level of graininess. Some of the control variables that were tuned in the program are listed below:

- Sensitivity of the detail detecting algorithms
- Overall amount of FM screening
- Maximum clustering characteristics of AM dots
- Smoothness of AM to FM transitions
- Detail threshold
- Noise distribution
- AM and FM dot gain (to a limited extent)
- Pixel Ratio

Using optimized parameters and building these parameters in the executable program as defaults, some images were again generated and compared to the ones screened with commercial products. The CristalRaster screened image shows excessive graininess in the background, and the detail is somewhat blurred due to the excessive noise required to eliminate patterns. The Hybrid screened image shows a smooth background, rendered using semi-clustered dots at a 45° angle. There is more perceptible detail, due to the adaptive addition of noise. If the vertices of the cones are compared, it can be clearly seen that the Hybrid screened image looks sharper. The image screened using UGRA Velvet shows a much smoother rendering of flat areas, comparable to the one achieved by the Hybrid Screening program. There seems to be more noise noticeable in the edges of the cones in the Velvet screen. The edges are more sharply rendered using Hybrid algorithms. The Velvet Screening program allows for the noise factor to be determined prior to screening. All images were screened using a factor of 25.

Characterization of Dot Gain

It is known that FM screens show more dot gain than AM screens (Stanton & Warner, 1994). However, on Hybrid screens, several different dot structures may be found for the same level of gray, so different dot gain curves as a function of gray level may be expected for varying levels of detail. In other words, there is no single dot gain curve anymore, but rather a dot gain surface represented in three dimensions.

To assess the dot gain characteristics, a target was specially created, consisting of patches with increasing gray levels in the vertical scale and increasing amount of AM in the horizontal scale. The target was output to a MatchPrint proof and measured.

The three-dimensional dot gain surface can be seen in figure 24. The main difference in dot gain between AM and FM is found in the midtones, probably because in this region there are more clustered dots in the AM patches relative to the FM patches. Closer to the extremes, there is not a significant difference between dot patterns, mostly because fully clustered dots are not being used. In these areas, the dots in low detail areas are almost as dispersed as the FM dots. Even though the dot gain difference is not very noticeable in the MatchPrint proof, it may be more noticeable depending on the printing process to be used, definitely requiring the development of a different compensation technique. A simple algorithm to selectively compensate for dot gain, depending on the gray level and on the level of detail was developed and used in this project. Instead of using an array with all the dot gain data as measured in the target, a general formula for dot gain was used. Input variables are the maximum dot gain for detailed areas and the maximum dot gain for low detail areas.

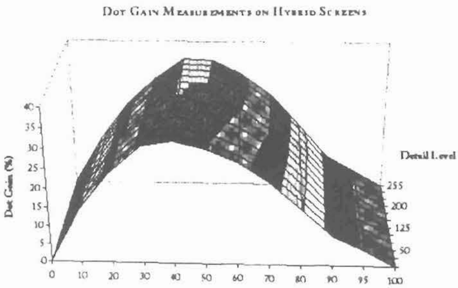

Figure 24. Dot gain curves for Hybrid Screening images on MatchPrint

Figure 25 shows the dot gain curves for AM and FM, calculated using a parabolic equation.

To predict dot gain for a given area, the program interpolates between the curves using the amount of detail as a weighting factor for FM and AM dot gain. In both curves, the maximum calculated dot gain occurs at the 50% dot, which is not always true in practice. The program can be modified to accept the dot area at which the dot gain curves reach the maximum.

Dot gain was no further investigated in this project due to time constraints.

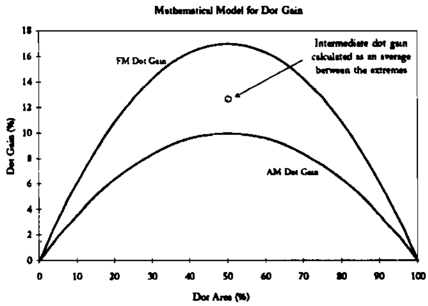

Figure 25. Calculated dot gain curves using parabolic functions

Analysis of Noise and Detail Rendering

After the tuning stage, some comparisons were made regarding the quality of the screened images, with a special target output to MatchPrint proofs. Enlargements (200%) simulations of the printed target are reproduced in figures 26 and 27, with Hybrid Screening at 600 dpi and a 75 lpi conventional screen.

The following observations on the original printed targets were made:

- There is subject moiré in the 150 lpi conventional halftone, resulting in a very unpleasant image (high frequency sinusoidal steps).
- The excessive noise used in CristalRaster FM screening results in jagged edges in the high frequency steps, also creating an unpleasant visual sensation.
- The high frequency steps in the UGRA Velvet FM screened image are well defined with much less noise relative to CristalRaster. However, there is an interference pattern, noticed as white vertical lines. Although not clearly understood by the author, it may be possible that some kind of periodic pattern is being mixed with the threshold levels in UGRA screens, in order to reduce noise.
- The detail rendering in the Hybrid Screening (MatchPrint proofs and figure 26) image is excellent, without any unnecessary noise and with no interference patterns, resulting in the most pleasant viewing sensation. As an example of what a Hybrid Screening image looks like, figure 28 shows an image output at 600 dpi (42 μm spot size). The default resolution for sheetfed press is 1200 dpi with a spot size of 21 μm.

Color Images

The implemented algorithms used a threshold array capable of generating 45° screens. When outputting color images, different screen angles are needed in order to avoid moiré patterns. However, the angles required for magenta (75°) and cyan (105°) have irrational tangents, requiring more complex techniques such as the supercell (Delabastita, 1992).
In order to simulate screen angles, the color separations of the original were rotated in Photoshop prior to screening with the Hybrid Screening program. The films were rotated back when making the color MatchPrint proofs.

The color image created with the Hybrid Screening program shows excellent detail rendering and no apparent graininess in the flat areas, especially if compared to the CristalRaster screened image. If compared to the Velvet screened image, though, the images appear to be similar in most areas, in terms of detail rendering as well as graininess. Some flat areas look different in the two images, and some edges appear to be sharper in the Hybrid image.

Figure 26. Enlargement of target printed with Hybrid Screening at 600 dpi

Figure 27. Enlargement of target printed with 75 lpi / 600 dpi

However, these are subjective evaluations. On the other hand, the rosette is visible in the Hybrid Screening image, at short distances, while there is no visible pattern in the Velvet image.

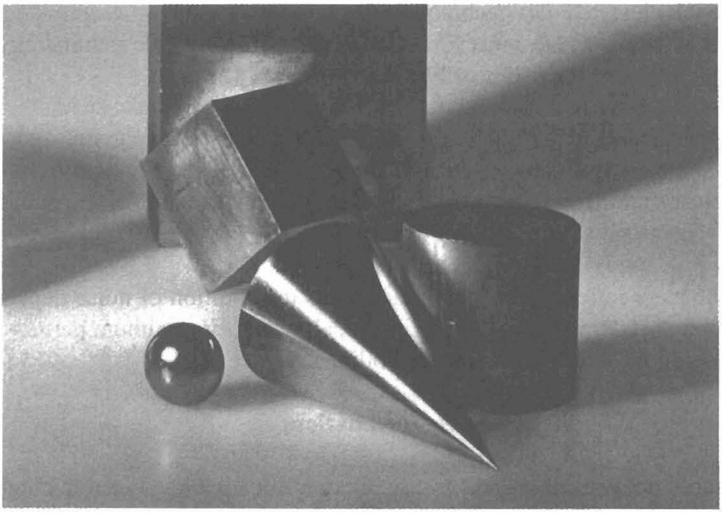

Figure 28. Hybrid Screening image output at 600 dpi

Adaptive FM Screening

After the hybrid screening program was developed, some research time was spent developing what the author called an Adaptive FM algorithm. This program uses regular error diffusion techniques to create frequency-modulated dots, but the amount of noise added to the threshold level depends on the level of detail, for which the detail-detecting algorithms were used. The minimum required amount of noise was experimentally determined, so that no extra perturbation that decreases the detail rendering capability is used.

A set of color separations was screened using the Adaptive FM program to create color images using MatchPrint. The detail edges are sharper than the ones reproduced with commercial screening products. However, there is still some graininess in the flat areas, where the UGRA Velvet screened image seems to perform better.

Conclusions

A rasterizing program was successfully developed, using a novel approach that mixes dispersed dot dithering (frequency modulation screening) with conventional clustered dot technique. The proposed goal of eliminating the graininess associated with most FM screening programs, while maintaining the detail rendering characteristics of FM screening was achieved.

The images generated by such technique proved to be comparable and even better, in some cases, to images created using commercial screening programs. It became clear that the concept works and has potential to improve the quality of color reproduction.

Another concept introduced in this project was the addition of noise depending on the amount of detail present in the image, allowing for minimum perturbation and increasing the detail rendering capabilities.

Recommendations

The clustered dot pattern may allow the ink to become clogged in some regions, if there is excessive dot gain on press. This factor may limit this technique to processes with reduced dot gain, such as waterless lithography. However, improvements in the algorithms can be made in such a way the dots start to cluster in a more ordered pattern, and always beginning from the center.
Further improvements will also require the possibility of creating different screen angles, by incorporating one threshold array per process color.
The program currently works with files in the raw format, but it can be modified to create "ready to run" files in tiff or any other standard format.
Further studies may concentrate on the development of hybrid algorithms with a minimum of dot clustering, and using information from all color separations to when screening each color.

References

Adobe Systems Incorporated (1994). Advanced Adobe Photoshop. Macmillan Computer Publishing.

Allebach, J. P. & Liu, B. (1976). Random Quasiperiodic Halftone Process. Journal of The Optical Society of America, Vol 66, No. 9, 909-917.

Billotet-Hoffman, C. & Bryngdahl, O. (1983). On The Error Diffusion Technique For Electronic Halftoning. Proceedings of the SID, Vol. 24/3, 253-258.

Delabastita, P. A. (1992). Screening Techniques, Moiré in Four Color Printing. TAGA Proceedings, 44-65.

Floyd, R. W. & Steinberg, L. (1976). An Adaptive Algorithm for Spatial Gray Scale. Proceedings of the SID, Vol 17, 75-77.
Ulichney, R. (1993). Digital Halftoning. The MIT Press, 4tth printing.
Oualline, S. (1995). Practical C++ Programming. O' Reilly & Associates, Inc, 1st edition.
Roetling, P. G. (1975). Halftone Method With Edge Enhancement and Moiré Suppression. Journal of The Optical Society of America, Vol 66, No. 10, 985-989.
Schläpfer, K. & Widmer, E. (1994). Are Fine Screens an Alternative to Frequency Modulation Screening? TAGA Proceedings, 34-41.
Schläpfer, K. (1994). Assessing Visual Noise Produced With Regular Screens and "Screenless" Techniques. TAGA Proceedings, 52-64.
Shammas, N. C. (1994). Teach Yourself Mac C++ Programming in 21 Days. SAMS Publishing, first edition.
Stanton, A. P. & Warner, R. (1994). Color Reproduction Characteristics of Stochastically Reproduced Images. TAGA Proceedings, 65-91.
Stutzman, M. (1994). Tone Correction for Stochastic Screening. GATFWorld Vol 6, issue 6.
Widmer, E., Schläpfer, K., Humbel, V. & Persiev, S. (1992). The Benefits of Frequency Modulation Screening. TAGA Proceedings, 28-39.