Enhanced Mottle Measurement

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Abstract

The characterization of mottle, both for unprinted substrates and printed material, is becoming an increasingly important metric to predict and measure the quality of hardcopy output. Currently there are three methods commonly in use: Visual examination and comparison to some standard samples; use of a camera or scanner and image processing software to evaluate mottle using a method based on the ISO/IEC 13660 standard algorithm; and quantitative analysis with a vision system that allows tailoring of the algorithm to separate the components of the mottle artifacts.

Mottle is a defect that can certainly degrade the perception of the quality of a print. Perception is dependent on several factors, including spatial frequency (size), contrast, sharpness, and viewing conditions (including illumination and distance). Therefore, mottle should be characterized taking these factors into consideration.

If elimination or minimization of mottle is desired in order to improve the quality of the end product, the detection of mottle is necessary but not sufficient. Quantitative analysis provides the data to identify components comprising the mottle, allowing causal relationships to be established.

This paper will detail two methods of quantifying mottle. One uses variable high pass spatial filters to separate the frequency components of the variation in the uniformity. The other characterizes the actual non-uniformity as cluster-type defects and allows quantification by size, contrast, and morphology.

Introduction—Description of Mottle

Mottle is usually defined as the blotchy variation in reflected intensity (or density) for nominally uniform printed or unprinted surfaces. There are several manifestations of such nonuniformities in the world of printed hardcopy output. They are all generally characterized as mottle, but are differentiated by their size. Several examples include graininess and granularity (usually smaller sized defects or high frequency variation), and mottle (defined as larger defects or lower frequency variation). Each has a different cause, so independent characterization and identification is required to provide detection and appropriate corrective action (process and quality control). For the remainder of this paper, the process of independent characterization will be referred to as separation of variables.

Analyses of media and print quality are generally used for one of two purposes. The first is relative or comparative—such as those used for competitive benchmarking. For this purpose, all that is required is a quantitative metric that yields a relative number that can be scaled for overall quality and thresholded for acceptability. The comparative metric may or may not report the aggregate effects due to multiple causes. The second purpose is process or quality control. Here is it critical that any components of the defects be detected and characterized to determine (or verify) their cause to enable tracking and correction. In this case, absolute quantified results are required.

Examples of each type of approach will be described in the following sections, along with a methodology that allows extraction of discrete quantifiable results from an integrated relative metric.

Mottle Variables and HVR

The objective characterization of mottle should correlate to the human observer's capability to perceive such nonuniformity. There are two primary components to this phenomenon: size (spatial frequency) and contrast (difference from the integrated average intensity). The variable of contrast has two possible manifestations. The perceived defects can be either darker or lighter than the integrated average. As noted above, differences in size may be attributable to differences in cause. Likewise, differences in polarity are usually indicative of disparate sources of the problem.

While instrumentation exists to characterize mottle to any resolution in both size and contrast, it serves no practical purpose to detect and eliminate mottle that is not perceptible by the human visual system. There are limits to the range of defect size detectable, defined in terms of spatial frequency. Since visual acuity is defined in terms of solid angle subtended, considering components in terms of spatial frequency allows broader relevance to applications designed for different viewing distances. However, the visual acuity relationship is affected by context. In other words, both the absolute intensity level and the contrast affect the limits of perceptibility. Therefore a complete characterization of mottle must be a matrix of both these variables, namely size and contrast.

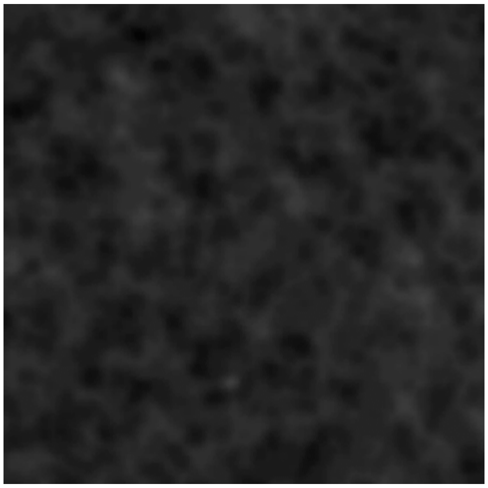

Figure 1. Example of a mottled surface.

Measurement Methods and References

There are a number of methods in the public domain to quantify mottle. Some, such as the specific perimeter algorithm proposed by Trepanier, Jordan and Nguyen[1,2] attempt to deal with size (here normalized by area), but ignore contrast. Others, such as the mottle index defined by Armel and Wise,[3] incorporate contrast, as well as size (in this case by using specific perimeter as an input). Yet others, such as stochastic frequency distribution analysis described by Rosenberger,[4] concentrate on contrast variation.

Fourier analysis is another method that has been used to characterize the frequency content of mottle. An application that is an extension of two-dimensional Fourier analysis is that of wavelet theory, proposed for texture classification by Sebe and Lew.[5]

There is a method (that will be examined in detail) specified in the ISO/IEC 13660 international standard on image quality[6] that attempts to combine size and contrast. It deals with size using a single high-pass filter that both limits the range of frequencies detectable, and combines those detected in a way that they can't be deconvolved. This makes it useful (in this formulation) only for comparative, not causal, analysis. It is, however, expandable in a way that makes it truly quantitative.

Another method (cluster-based) has been developed by Wolin[7,8] and colleagues that explicitly characterizes mottle in terms of size and contrast. In doing so, it also allows the use of additional image analysis tools that can provide supplemental information on morphology and locations of the mottle artifacts, which could be helpful in identifying sources of the defects.

ISO/IEC 13660 (Tile) Method

The mottle measurement in the IOS/IEC 13660 standard requires that an area of at least 20mm x 20mm be sampled at a resolution of 2mm x 2mm, where the average density (related to intensity) in each cell is measured, and then the standard deviation of these values is calculated. This definition effectively restricts the size of the defects detected to 2mm or smaller (a frequency of .5cycle/mm and higher), and in fact is a high pass filter that combines the contributions of all higher frequencies. The resultant metric is a single number, but since it integrates many components, it is only useful for qualitative comparison.

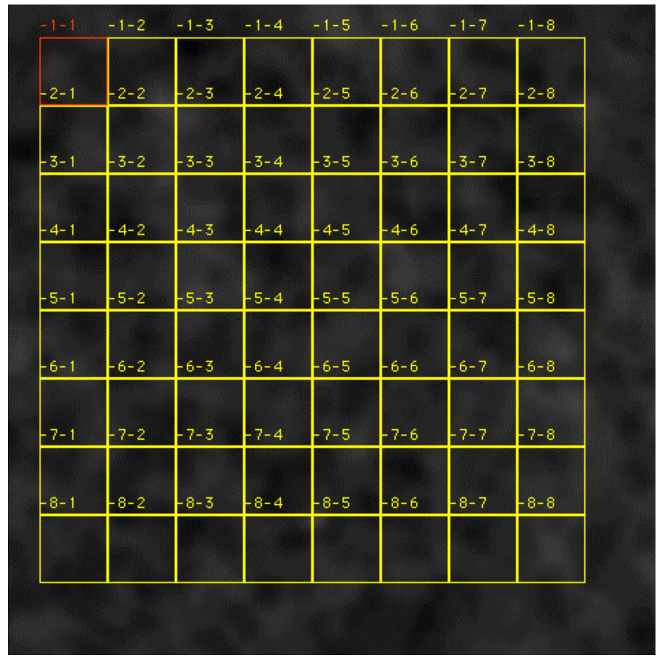

Figure 2. Example of tiles.

This method can be modified and expanded to provide more discrete data, useful for quantitative analysis in determining the components of mottle. By varying the sampling resolution, effectively changing the spatial frequency filter, the different size components of mottle can be separated and characterized. Smaller cells will isolate higher frequencies, while larger ones will include lower frequency uniformity variations. Increasing the total area measured will also increase both the statistical significance of the results, and the size range of mottle components that can be characterized.

In addition, other algorithms can be used to extract uniformity data from the samples. While the standard deviation of all the average densities (intensities) for each sample is the metric defined in the standard, other potentially useful analyses include the average of the standard deviations, and the standard deviation of the standard deviations (see Table 1). Each of these characterizes mottle differently. The standard deviation of the averages gives an indication of the "uniformity" of the mottle at the specific sampling rate (*e.g.* 2 mm x 2mm). A uniform distribution of mottle at this spacing or some even divisor of this spacing would result in similar values, which would translate into a low standard deviation of averages. On the other hand, the average of the standard deviations indicates the overall variation of the measured area.

Table 1. Tile method mottle metrics.

cell size	ave	std of ave	ave of std	std of std
4mmx4mm	23.168	2.070	5.903	0.837
2mmx2mm	23.168	3.304	5.237	1.169
1mmx1mm	23.168	4.777	3.889	1.297

Cluster Method

Explicit characterization of the contrast and frequency content of nonuniformity is the purpose behind the cluster method of mottle analysis. In this approach, mottle analysis is based on clusters. Clusters are defined as contiguous regions of pixels that fit certain pre-defined criteria in terms of size and contrast. Different size and contrast bins are constructed to examine the spatial content of the mottle as well as the brightness content. The size limits define an effective area or radial dimension, while the contrast range allows for specification of both polarity (light or dark) and amplitude.

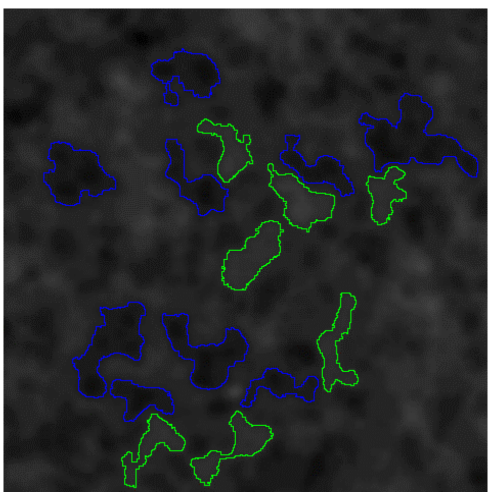

Figure 3. Example of cluster identification.

A typical set-up uses a series of different size bins (0.5-1 mm effective diameter, 1-2 mm effective diameter, 2-4 mm effective diameter …). Contrast limits are usually defined according to the range of samples. For example, test set-up might include bins that identify clusters of specific sizes that are between 1-2 gray levels different than the average gray level within the region of interest (ROI), 2-4 gray levels different than the average, and 4-8 gray levels different than the average (see Table 2).

Table 2. Number of clusters (light,dark).

contrast/ diameter	1-2 grey levels	2-4 grey levels	4-8 grey levels
.5mm - 1mm	4,14	12,18	17,20
1mm - 2mm	2,19	8,14	11,19
2mm - 4mm	9,9	6,12	7,9

Once clusters of specific sizes and contrasts are counted, a weighted sum can provide a single number for first order comparative analysis. Generally, this weighted sum is constructed to apply weights to sizes and contrasts based on the human visual acuity function. However, in addition to reporting this one comparative number, maintaining the individual bin data allows the user to trace mottle back to its component parts and potentially aid in separation of variables to support root cause analysis. Additional variables such as perimeter length (see Table 3) and axis ratio (see Table 4) can provide supplemental characterization which can enhance discrimination in causal analysis.

Table 3. Perimeter (mm) of clusters (light,dark).

contrast/ diameter	1-2 grey levels	2-4 grey levels	4-8 grey levels
.5mm - 1mm	2.69,2.43	2.65,2.70	2.89,2.57
1mm - 2mm	5.17,4.65	5.37,4.55	7.06,6.68
2mm - 4mm	n/a,13.59	12.53,13.36	12.32,14.17

Table 4. Axis ratio of clusters (light,dark).

contrast/ diameter	1-2 grey levels	2-4 grey levels	4-8 grey levels
.5mm - 1mm	0.72,0.67	0.65,0.68	0.63,0.67
1mm - 2mm	0.52,0.67	0.63,0.68	0.55,0.59
2mm - 4mm	n/a,0.60	0.57,0.62	0.47,0.55

Conclusions

While there are numerous methods to characterize the perceptual phenomenon of mottle for both printed samples and unprinted substrates, care must be used in choosing the appropriate one in order to get applicable results. In cases where quantitative data is required for analysis of the relationship between cause and effect, two methods have been described that allow the separation of variables necessary. Both methods use standard image processing tools currently available.

References

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Biography

Dave Wolin is Vice President of Business Development at ImageXpert Inc. After receiving his Bachelor's degree in Physics from Cornell University, Dave has spent the last twenty years working in the field of imaging. He has been involved in the development and production of imaging sensors and systems for a variety of applications. His work at ImageXpert has included metric development for image quality analysis of printers and media.