Densitometer and dot area

Today many still use a densitometer for evaluation of a print test. Specifically it is done for looking at the actual halftone dot area coverage relative to what was defined in the print design. *Wilbert Streefland* questions this practice.

The results of these tests are accepted blindly but should they be? There is nothing wrong with the proposed method of using a densitometer nor is there anything mathematically wrong with the use of the Murray-Davis and Yule-Nielsen equations for calculating the dot area from densitometer readings but is the effect of the error in the density measurement reading on the end result, the evaluated covered area, really well understood? Might it not be that the error in the measurements can result in meaningless results?

What is needed to be learned in the industry is improvement of knowledge by challenging experiences by means of a mathematical module. Thus being able to explain the experiences based on a mathematical model helps to develop quantitative knowledge of the subject.

Today there is more knowledge and technology available than at the time the first densitometer was developed. Why not use it?

It should be borne in mind that 'improving' does not only mean that to do what has always done better but points towards also to doing different things.

The problem

The accuracy of estimating the printed coverage of a halftone area by using a densitometer for measuring it based on the light reflection of a full tone area being 100% and an unprinted area being 0% is largely influenced by the reading accuracy of the instrument used for measuring the light reflectance, especially when a logarithmic function is used before displaying the results of the reading.

What one needs to understand is the influence of the reading accuracy on the end result.

The other question one can ask is if it is really important to calculate a dot area coverage value from the measured density values for the halftone area? Would it not be sufficient to show the relation between the halftone dot area used in the image and the corresponding printed density value? After all a scanner is used to measure density in the original, thus it would be easier to have a table that links the printed density to the dot area coverage to be used in the design image. This table can be used to select the coverage needed in the image based on the scanned density.

Take a closer look at the densitometer measuring principle and the involved equations.

The theory

First the measuring principle of a densitometer for measuring colour density.

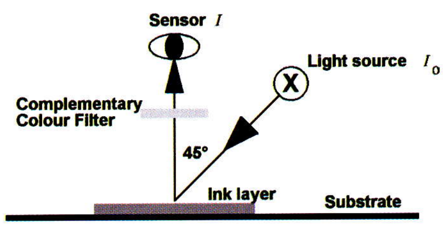


Figure 1: Measuring principle densitometer.

It starts with the densitometer sending white light to the substrate and measuring the reflected light from the substrate, see figure 1 for an illustration, using complementary coloured filters. Following the equation for colour density:

$$D = \log\frac{I_0}{I}$$

D = Colour density
I_0 = Light send (100%)
I = Light returend (between 0-100%)

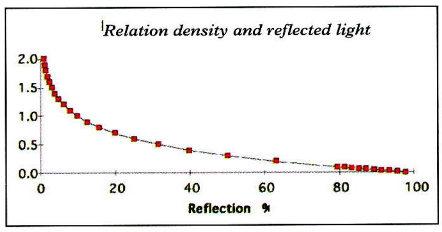
The following table shows the complementary coloured filters used by the densitometer for measuring the density of process colours:

Measured process colour:	Filtered colours:	Complementary colour of the filter used for measuring density:
Yellow	Red + Green	Blue
Magenta	Red + Blue	Green
Cyan	Green + Blue	Red
Black	Non	Transparent

If the equation is used that the densitometer uses for calculating the density value the following table is created:

Light send	Light returned	Density calculated
100 %	1.00 %	2.00
100 %	10.00 %	1.00
100 %	50.00 %	0.30
100 %	97.72 %	0.01

Graph 1 shows the logarithmic relation between the density value calculated and the percentage of reflected light measured.



From the measured density it is possible to calculate the halftone area coverage of print assuming that there is a full tone area in the same colour printed. What is done is that the densitometer is 'zeroed' on the unprinted area, measure the density in the full tone area and in the halftone area from which the coverage is needed to be known. The two density values are then entered in an equation. The most commonly used equation is the: Murray-Davis equation

This is based on the assumption that there is a relation between the density and the size of the printed and the unprinted area in a fixed area.

The Murray-Davis equation:

$$C_a = \frac{1-10^{-D_h}}{1-10^{-D_f}} * 100$$

C_a = Percentage covered area
D_f = Density full tone area
D_h = Density halftone area

Often the Yule-Nielsen equation is used.

This adds a constant to the Murray-Davis equation to correct for the difference in light reflection between a printed area and unprinted area. This constant is related to the properties that influence the reflections of the non-printed area. There is no difference between the Murray-Davis and Yule-Nielsen equations if the constant value is 1.

The Yule-Nielsen equation:

$$C_a = \frac{1-10^{\frac{-D_h}{n}}}{1-10^{\frac{-D_f}{n}}} * 100$$

C_a = Percentage covered area
D_f = Density full tone area
D_h = Density halftone area
n = Yule - Nielsen constant

Mostly the industry speaks about dot gain being the difference between the coverage of the halftone area in the design and the actual printed coverage. Let us have a look at the: Linear dot gain equation.

The linear dot gain equation is a mathematical presentation of how the dot size might change by varying one parameter in a calculation model. The design of the equation is based on three assumptions:

1. A full tone area has no dot gain;
2. Each halftone area can become only a 100% covered area if there is maximum dot gain;
3. There is a linear relationship between the amount of dot gain of all halftone areas.

The linear dot gain equation:

$$C_{a\_cor} = C_a + (100 - C_a) * \frac{a}{100}$$

C_{a_cor} = Corrected percentage covered area
C_a = Percentage covered area film
a = Covered area constant (0 - 100)

The covered area constant can only have a value between 0 and 100. If the covered area constant is 0: Ca_cor = Ca. If the covered area constant value is 100 the value of Ca_cor = 100 independent of the value of Ca.

So it is now known what formula to use but what is the consequence of a reading error (or the reading accuracy) on the calculated halftone dot area coverage? For this part only the Murray-Davis equation is used.

Error on dot area using Murray-Davis equation

A backwards calculation is needed to understand the problem better. Here is an example. What density is expected to be measured if the full tone density is 1.2 when using the Murray-Davis equation? The following table shows the result:

Dot %	Calculated density	Dot% Error half tone
100	1.200	0.30
90	0.805	0.75
80	0.601	1.20
70	0.463	1.65
60	0.359	2.10
50	0.274	2.55
40	0.204	3.00
30	0.143	3.45
20	0.090	3.90
10	0.043	4.35
5	0.021	4.58
3	0.012	4.67
2	0.008	4.71

Table 1: Density calculation of halftone coverage based on a given full-tone density and the error resulting from a 0.02 density reading error

If it is assumed that the reading accuracy of a densitometer is 0.02 then how can a reliable value for halftone areas below 30% be detected? The impact of a 0.02 density reading error on the halftone values has been calculated. The result is that a 20% coverage area has a tolerance of 3.9%. This can be wrong by 20% and it gets worse for a 2% area.

The writer would not advise using density readings for any corrective action on the designed image.

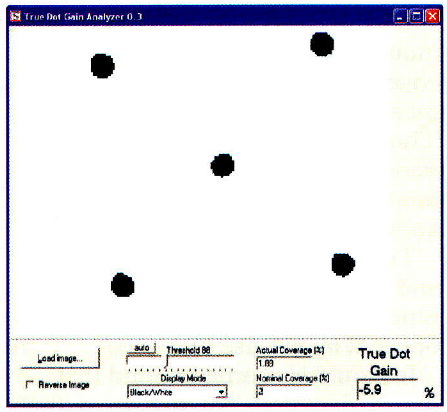
Using image analysis for dot area

So what can be done differently? The image analysis could be used to look at the actual dots. Also here there is the influence of the device collecting the image but every day new improved devices are introduced having a higher resolution. The error is made on the edge where it is decided if the area is printed or unprinted. The error is then linked if the pixel in the sensor (camera) looking at the edge provides a correct contrast value to decide that this pixel belongs to the printed area or not.

USB digital microscope.

The writer's partner, Tony Sullivan developed a software tool, which can be used with a digital microscope, to determine the covered area with dots from an image. The digital microscope used was one directly connected to the USB port of the computer. It is a low cost device and works fine. The size of one pixel on the image chip in the USB digital microscope is equal to 2.55 µm in the image.

The following image is a screen of the program. It is the result of evaluating a 2% area of a positive film. The reading of the system shows a value of 1.88%. The individual pixels that make the dot can be seen. A higher resolution sensor would make the system more accurate. This method might not have the risk of a 20% error on the reading.



Conclusion

Using densitometer readings for calculating the dot area coverage from a halftone area might have a large error if the density reading accuracy/resolution of the densitometer is low (0.02).

Care should be taken when using readings that have been derived using a logarithmic function.

Using image analysis might be a more reliable method for measuring the coverage of a halftone area.

Recommendation

'Dot gain curves' would be better replaced by a curve showing the relationship between the dot area used in the image design and the actual measured density in the image.

The image analysis in combination with the USB digital microscope can be used to monitor dot size variation during production. ■