Densitometer and dot area

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Many in the industry still do it today: 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.

We accept the results of these tests blindly – but should we? 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 we need to learn and accept in our industry is to improve our knowledge by challenging our experiences by means of a mathematical module. Thus being able to explain our experiences based on a mathematical model helps to develop quantitative knowledge of the subject.

Today we have more knowledge and technology at our fingertips than at the time the first densitometer was developed. Why not use it?

We need to keep in mind that »improving« does not only mean that we do what we always have done better, but also points towards 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 un-printed 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 it 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 for measuring density in the original. 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.

Let us take a closer look at the densitometer measuring principle and the equations involved.

The theory

First we will look at the measuring principle of a densitometer for measuring colour density (*figure 1*).

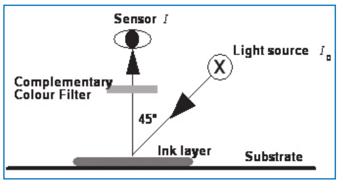

Figure 1: Measuring principle densitometer.

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 sent (100%)
I = Light returned (between 0–100%

Table 1 shows the complementary coloured filters used by the densitometer for measuring the density of process colours:

If we use the equation that the densitometer uses for calculating the density value we can create *table 2*.

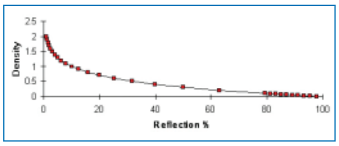

Figure 2: Relation of density and reflected light.

Figure 2 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 we have a full tone area in the same colour being printed. The densitometer is »zeroed« on an unprinted area and the density measured in the full tone and halftone areas from which we want to know the coverage. The two density values are then entered into an equation. The most common used equation is the MURRAY-DAVIS equation. This equation is based on the assumption that there is a relation between the density and the size of the printed and unprinted area in a fixed area. The MURRAY-DAVIS equation:

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

C_a = Percentage covered area
D_f = Density fulltone area
D_h = Density halftone area

But also often the YULE-NIELSEN equation is used.

Tables 1 and 2.

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	None	Transparent

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

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The YULE-NIELSEN equation 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:

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

C_a = Percentage covered area
D_f = Density fulltone 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.

This 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 never has dot gain;
2. Each halftone area can only become 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:

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

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: $C_{a\_cor} = C_a$. If the covered area constant value is 100 the value of $C_{a\_cor} = 100$ independent of the value of C_a.

So now we know which formulae are used but what is the consequence of a reading error (or the reading accuracy) on the calculated halftone dot area coverage? For this part we will only use the MURRAY-DAVIS equation.

Error on dot area using Murray-Davis equation

We need to do a backwards calculation to understand the problem better. Let me give an example. What density do we expect to measure if the full-tone density is 1.2 when using the MURRAY-DAVIS equation? *Table 3* shows the result.

If we assume that the reading accuracy of a densitometer is 0.02 then how can we detect reliably a value for halftone areas below 30%? We have calculated the impact of a 0.02 density reading error on the halftone values. The result is that a 20% coverage area has a tolerance of 3.9%. Thus can be wrong by 20%! And it gets worse for a 2% area.

Personally I would not promote the use of density readings for any corrective action on the designed image.

Using image analysis for dot area

So what can we do differently? We could use image analysis to look at the actual dots. Also here there is the influence of the device collecting the image but every day new improved devices have been introduced having a higher resolution. The error is made on the edge where we have to decide if the area is printed or unprinted. The error is then linked to the fact: whether the pixel in the sensor (camera) looking at the edge is providing a correct contrast value to decide whether this pixel belongs to the printed area or not.

My 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 I used was directly connected to the USB port of my 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 micron in the image.

Figure 3 is a screen shot 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%. You can see the individual pixels that make the dot. A higher resolution sensor would make the system more accurate. This method might not have the risk of a 20% error on the reading.

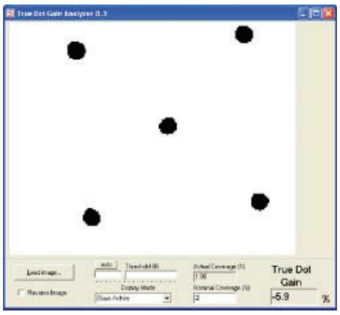

Figure 3.

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).

Always be careful 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 relation between the dot area used in the image design and the actual measured density in the image.

Image analysis in combination with the USB Digital Microscope can be used to monitor dot size variation during production. ■

Dot%	Calculated density	Dot% error halftone
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 3: Density calculation of halftone coverage based on a given full-tone density and the error resulting from a 0.02 density reading error.