DENSITOMETER AND DOT AREA

Many of you still do it today — use a densitometer for evaluation of a print test. It is done to check the actual halftone dot area coverage relative to what was defined in the print design. We accept the results of these tests blindly but are we supposed to? 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 evaluated area really understood? Might it be that an error in the measurement can result in meaningless results?

What we need to learn is to improve our knowledge by challenging our experiences by means of a mathematical modules, thus being able to explain our experiences based on a mathematical model that 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?

The problem

The accuracy of estimating the printed coverage of a halftone area using a densitometer is based on the light reflection of a full tone area being 100 per cent and an unprinted area being 0 per cent. This is obviously influenced by the reading accuracy of the instrument used, 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.

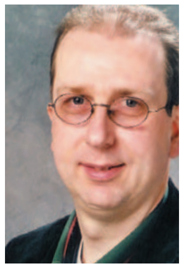
The other question one can ask is if it is really important to calculate a dot area coverage value from the measured density values for the halftone area? Would it not be sufficient to show the relation between the halftone dot area used in the image and the corresponding printed density value? After all, a scanner is used to measure density in the original. 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.

It starts with the densitometer



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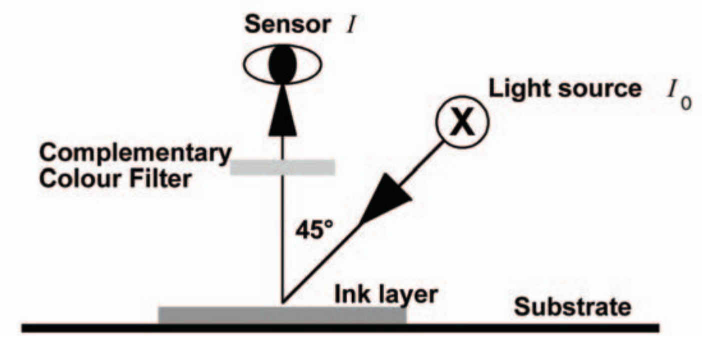


Figure 1: Measuring principle densitometer.

sending white light to the substrate and measuring the reflected light from the substrate (see figure 1), using complementary coloured filters.

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

D = Colour density

I_0 = Light send (100%)

I = Light returend(between 0-100%)

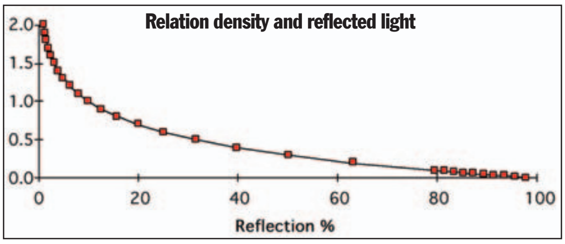
The following table shows the complementary coloured filters used by the densitometer for measuring the density of process colours:

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 we use the equation that the densitometer uses for calculating the density value we can create the following table:

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

The graph below 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 printed. We "Zero" the densitometer on an un-printed area and then measure the density in the full tone area and in the halftone area from which we want to know the coverage. The two density values are then entered in an equation. The most common 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

There is also the Yule-Nielsen equation which 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 unprinted 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

The industry normally speaks about dot-gain being the difference between the coverage of the halftone area in the design and the actual printed coverage. Let's have a look at the linear dot gain equation. This 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:

— A full tone area has no dot gain;

— Each halftone area can only become a 100 per cent covered area if there is maximum dot gain;

— 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 now we know what 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 exercise we will only use the Murray-Davis equation.

Error 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 1 shows the result:

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.

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

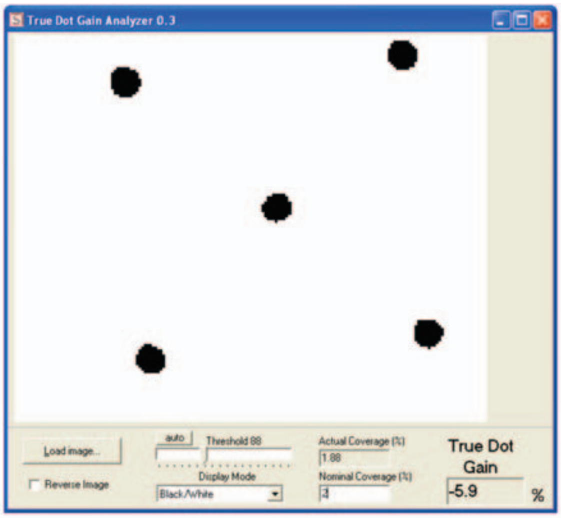
If we assume that the reading accuracy of a densitometer is 0.02 then how can we detect a value for halftone areas below 30 per cent? We have calculated the impact of a 0.02 density reading error on the halftone values. The result is that a 20 per cent coverage area has a tolerance of 3.9 per cent. This can be wrong by 20 per cent! And it gets worse for a 2 per cent area. I would therefore not recommend the use of density readings for any corrective action on the designed image.

Image analysis for dot area

So what can we do differently? We can use image analysis to look at the actual dots. Bear in mind the influence of the device collecting the image, but all the time, new improved devices are introduced with higher resolution. The error is made at the edge where we have to decide if the area is printed or unprinted. The error is then linked to the pixel in the sensor (camera) looking at the edge, providing a correct contrast value to decide if this pixel belongs to the printed area or not.

A colleague of mine 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 one 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 μm in the image.

The following image is a screen of the software tool. It is the result of evaluating a 2 per cent area of a positive film. The reading of the system shows a value of 1.88 per cent. You can see the individual pixels that make the dot. A higher resolution sensor would make the system more accurate. This method



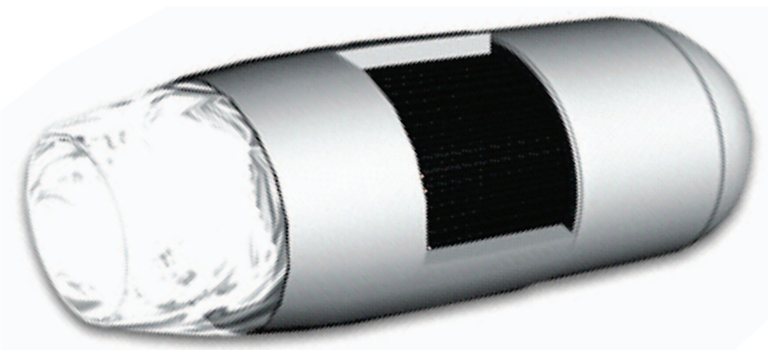
might not make a 20 per cent error in the reading.

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). 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 of the image. The image analysis in combination with the USB Digital Microscope can be used to monitor dot size variation during production.



USB Digital Microscope

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