Optimization Algorithm that Generates the Lowest ΔE_{ab} Values to a Reference Standard Based on Spectral Measurements of Solid Inks in Offset Lithography

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Abstract

ISO 12647-2 specifies CIELAB values for primary and secondary colors, but only tolerances for the primary solid colors. Press operators in lithography still favor density measurements for process control to assure quality and reproducibility during a production run. Since there is no direct relationship between density and CIELAB measurements, there is a gap between what the standard specifies and what the industry is actually doing.

This research investigates the possibility of using the tolerances specified for the primary colors to achieve a better conformance of the secondary colors. Combining Beer's Law and Hamilton's Trapping Equation into an algorithm provides a method to predict the outcome of resulting secondary colors if the ink layer thicknesses of one or more of the primaries are altered. The research goal was to provide the press operator with a set of rules and applications to help him or her make decisions on how to reach the primary and secondary aim points for an OK sheet in as few steps as possible.

The algorithm was tested against 197 different measurements for all six colors (C, M, Y, R, G, B), simulating 197 different printing conditions. The results show that the algorithm has high degree of accuracy in predicting the ink layer thickness that conforms to ISO 12647-2 aim point, but errors in the prediction occur when the measured sum of the secondary colors have a low ΔE_{ab} to the standard.

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Introduction

For many years density measurements has been the industry standard to perform process control on the press. Density measurements of the process ink patches offer the press operator a simple method to measure the effect of ink layer thickness on the paper so, if necessary, adjustments to the ink fountain keys can be made to achieve the ink layer thickness that produces the desired color. Adjusting the ink fountain keys according to established density aim values enables faster fine adjustments using fewer sheets (Dejidas & Destree, 2005). Printing companies are always looking for new ways to shorten makeready time on the press to optimize productivity. One of the most time consuming tasks during the makeready is to adjust the ink layer thickness to achieve the right color for the OK print, which is used as a reference print during production.

The International Organization for Standardization (ISO) published the second edition ISO 12647-2 standard for Offset lithographic processes in 2004. One of the major changes in the update was the shift from specifying primary and secondary inks aim points as densities to colorimetric values. ISO 12647-2 lists values or sets of values of the primary parameters that are specified in ISO 12647-1 and related technical properties of a half-tone offset lithographic print. Primary parameters include the screening, the tone value increase, and the colors of the solids, their overprints and the print substrate. Conformance to the specified values in proof and production printing assures, in principle, a good visual match between specimens produced. The specified parameters and values were based on a set of limited tests conducted in a controlled facility. During the following years industry experts like Fogra, BVDM and UGRA found it nearly impossible to hit the target values for both the primary and the secondary colors, and ISO's technical committee decided in 2007 to revise the standard and update some of the parameters. The secondary colors red (M+Y), green (C+Y) and blue (C+M) depend on conditions that include the printing sequence, the rheological and transparency properties of the inks, mechanics of the press and the surface characteristics of the print substrate. This means that color conformance of the primaries cyan (C), magenta (M) and yellow (Y) is not sufficient for the conformance of the secondary colors (ISO 12647-2, 2004). Even though ISO changed the secondary colors aim points in 2007, it is a still difficult for the industry to achieve the colorimetric values specified for the overprint colors and for many companies measuring density values is still the preferred process control parameter.

ISO only specifies tolerances for the primary colors. This research will investigate the interaction between the inks given they are within the tolerances, and the fact that change in one of the primary colors affect two of the secondary colors. The result of this research provide a method to predict the outcome of the secondary colors if the ink layer thicknesses of one or more of the primaries are altered. If the secondary colors can be predicted, an algorithm can be build that selects the ink layer thickness of the primary colors that returns the lowest ΔE_{ab} for the secondary colors and provide the press operator with a new set of density aim values for a quick makeready that conforms to the ISO standard.

Literature review

Reading different forums on the Internet shows that there is still a lot of confusion in some printing companies about what the Standards specify in terms of measuring color on a control bar. In a discussion at PrintPlanet.com's (2014) forum, the topic posted is "Standard ink densities?" Out of 95 replies to the posting about 25% of the users, suggest different density aim values that they say conform to "the standards".

The above example is just one out of many postings where the users seems confused about what the difference between process control and printing to the standard means. In an article for IPA Bulletin, David McDowell (2004) made similar observations and stated "I have recently noticed that in many printing related forums and discussions the topics of process control, color characterization, and color management profiles are often confused and intermixed."

The standard

The ISO 12647-2 specifies a set of parameters for the offset lithographic processes. For the purpose of this research the only parameters that is necessary to describe is the aim values for primary process color solids (CMYK), two- color overprints (RGB), and tolerances (ΔE_{ab}).

The aim values for process solid colors and the two-color overprints are specified as CIELAB coordinates with the ink sequence: Black, Cyan, Magenta, and Yellow. ISO specifies a tolerance of ΔEab 5.0 between aim values and the color OK print for process solid colors. ISO does not specify any tolerances for the two-color overprints but does specify suggested aim points.

ISO published the first standard for offset printing in 1996. Even though the standard recommends the use of CIELAB values, an informative table in Annex B shows the density values for the process colors. When ISO updated the standard in 2004, it removed all traces of density as aim values.

Process control

Process control in an offset lithographic pressrun involves periodical inspection and qualification of the press sheets pulled from the press. The press operator measures patches on a color control bar to ensure that solid ink aim values, tone value increase, and trapping are achieved and maintained on the running press (Dejidas & Destree, 2005; McDowell, 2004).

There are two different methods of measuring solid ink patches that can be used for process control: Density and CIELAB.

Density measurements for process control

Density is a measurement of the effect of ink layer thickness of a process ink. Ron Ellis (2009) suggests the use of density measurements for daily production and only use CIELAB measurements for troubleshooting. This is to some extend in compliance with the standard. Even though ISO removed density aim values, this paragraph was kept in the standard.

Density values can be very valuable for process control during a print run, where the instrument, the ink and the print substrate remain the same. However, in a general situation, density values do not define a color to the required degree…. (ISO 12647-2:2004, 2004)

That paragraph must be interpreted as recognition, that density values are still valuable as process control measurements.

CIELAB measurements for process control

Using CIELAB measurements for process control is more accurate than using density values because CIELAB describes the actual color. The problem with using CIELAB for process control is that the CIELAB color space is three- dimensional, which means that the press operator has to relate to three values for each color (L*, a*, and b*) instead of just one for density measurements. Another drawback is that there is no direct relationship between CIELAB values and the corresponding ink key adjustments (Hutcheson, 2008; Kipphan, 2001).

Don Hutcheson (2008) presents a table where the press operator can learn about the relationship between adjusting CIELAB- and density values.

Ink	More Density	Less Density	Notes
All	L* down	L* up	(L* moves opposite to density)
Yellow	L* down, b* up	L* up, b* down	(b* moves much faster than L*)
Magenta	L* down, a* up	L* up, a* down	(b* can increase with excess density)
Cyan	L* down, b* up	L* up, b* down	(a* doesn't move much)
Black	L* down	L*	(a* and b* hardly move at all)

Table 1: *Don Hutcheson's table on the effect of Ink Density Changes on L*a*b* Values*

Instead of using all three values from CIELAB, Don prioritizes each dimension in CIELAB, so the press operator can focus on just one or two values.

John Seymour (2007) wrote a TAGA paper on converting from the ΔE_{ab} variation tolerances in ISO 12647-2 to densitometric tolerances. The research concludes that there is a theoretical relationship colorimetric and densitometric measurements and that the following table can be used for those conversions.

	ΔE_{ab} (ISO)	ΔD (coated)	ΔD (uncoated)
Cyan	4	± 0,16	± 0,10
Magenta	4	± 0,14	± 0,09
Yellow	5	± 0,08	± 0,07
Black	4	± 0,15	± 0,11

Table 2: *John Seymour's conversion table*

Equations used in the algorithm

Beer's Law

Beer's law states that when light passing through a liquid, its absorption is proportional to the concentration and the path length. By applying the law on a spectral wavelength basis the spectral reflectance of different ink layer thicknesses can be calculated (Hoffman, 1998; Berns, 2000).

$$R_{(\lambda)} = 10^{-\left[\left((R_{0(\lambda)} - R_{p(\lambda)})*m\right)+R_{p(\lambda)}\right]} * 100 \qquad \text{Eq. (1)}$$

where:

> R0 is the spectral reflectance of an ILT. Rp is the spectral reflectance of the paper. *m* is a multiplier for increasing or decreasing ILT.

Subtracting the spectral reflectance of the paper from the nominal spectra gives the relative spectral reflectance of the ink layer. The multiplier is then used to approximate the effect of a change in ink layer. By changing the multiplier in small increments simulates different ink layer thicknesses and returns will be used to predict the spectral reflectance of a range of ILT's. Small increments will give a higher resolution in the predicted range. The paper reflectance is added back to convert to absolute reflectance.

Trapping

Trapping is an expression of how well one color ink layer is adhering to a previously printed ink layer. Since paper and ink have different adhesion characteristics, the ink layer thickness will normally be different when printed on the two surfaces. Trapping from density measurements is calculated using Frank Preucils (1953) formula for density based ink trapping.

The formula shows that Trapping % = {(Density of overprint – Density of 1st printed ink) / Density of 2nd printed ink} x 100 when the density is measured through the filter corresponding to the 2nd printed ink. This means that the result of the trapping formula is the percentage of the second color printed on top of the first color printed compared to the second color printed on paper.

Hamilton Trapping Equation

Recent research shows that predicting the two-color overprint is a difficult task because the trapping changes when the ink layer thickness of one of the primaries changes. Viggiano and Prakhya (2008) did a feasibility study where the use of different trapping models for overprint predictions was explored. The study showed that Hamilton's Trapping Equation produced accuracy levels for predicted overprint of less than 4.0 ΔE_{ab}.

Equation #2

$$D_{op,\lambda} = D_{\infty,\lambda} - (D_{\infty,\lambda} - D_{1,\lambda})\left[\frac{D_{\infty,\lambda} - D_{2,\lambda}}{D_{\infty,\lambda} - D_{p,\lambda}}\right]^{Th} \quad \text{Eq. (2)}$$

where:

Dop is the spectral density of the overprint
D1 is the spectral density of the first ink down
D2 is the spectral density of the second ink down
D∞ is the saturation density of the second ink down
Dp is the spectral density of the paper
Th is the Hamilton equation trap.

One of the problems with using Hamilton's Trapping Equation for overprint predictions, is that there are two unknowns in the equation: Saturation density and Trap. In 2011, Sigg, Viggiano & Husain did a research project on predicting the overprint of two spot colors using Hamilton's Trapping Equation. It used a method where both the trap value and the saturation density of the second ink were incremented, and for both combinations, the color difference to the actually printed sample was calculated. The research concluded a high accuracy in using the incremental method with Hamilton's Trapping Equation. The same method is used in this research.

Research Question

The result of this research will provide the press operator with an algorithm that calculates the optimal density values based on spectral measurements to achieve the lowest possible ΔEab values on both the primary and secondary colors.

The algorithm provides a method to predict the outcome of the secondary colors if the ink layer thickness of one or more of the primaries is altered. The research goal was to provide the press operator with a set of rules and applications to help him or her make decisions on how to reach the aim points for an OK sheet in as few steps as possible.

Research question

Is it possible to predict the optimal ink layer that generates the lowest ΔE_{ab} for the secondary colors aim values, while keeping primaries in conformance to ISO 12647-2?

Methodology

In the first part of this research, the procedure is to develop an algorithm that uses both Beer's Law and Hamilton's Trapping Equation to estimate the best possible conformance to a reference standard. By combining and implementing the equations into an algorithm it is possible to calculate what ILT of two primary colors that generates the lowest ΔE_{ab} for the two-color overprint compared to the aim values in ISO 12647-2. Since the conformance to ISO 12647-2 is critical, the algorithm will chose the lowest ΔE_{ab} for the two-color overprint, while the primaries still conforms to the tolerances specified in ISO 12647-2. The algorithm is written, tested and analyzed in MATLAB.

The second part of the research is to generate data that can be used to test the algorithm. A press run was utilized for this step.

The third part is to test the accuracy of the algorithm using the data collected from the press run.

Part 1: Building an algorithm that predicts the optimal ink layer thickness that returns the lowest ΔE_{ab} for both the primary and secondary colors.

A complete flowchart of the algorithm can be found in Appendix A.

Input:

The input for the algorithm is spectral measurements of Cyan, Magenta, Yellow, Red, Green, Blue, and Paper. These measurements are used as a basis for all the predictions done by the algorithm.

Process #1:

The spectral reflection measurements are used to predict a range of primary colors using Beer's Law, as described in the literature review. The result is spectral reflectance predictions representing different ILT's. From that range of ILT's of the primary colors, only those that are within a ΔE_{ab} of 5.0 to the reference standard will be used. The rest is discarded.

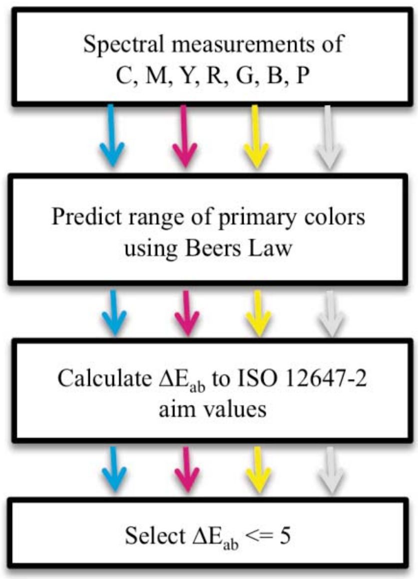

Figure 1: *Process #1 one of the algorithm*

Process #2:

Since ISO 12647-2 does not specify a tolerance for two-color overprints, any combination of the predicted ILT's using Hamilton's Trapping Equation will conform to the standard. The method of implementing Hamilton's Trapping Equation is described in the literature review. Because of the ink sequence (CMY), randomly calculating the two-color overprint will give inappropriate results. As shown in Figure 2 (Process #2), the same cyan ILT prediction is used to calculate Blue and Green. The same magenta and yellow ILT predictions are then used to calculate Red. This is all to do with the ink sequence and the fact that the one primary ink is used for two two-color overprints in the printing process. The result of this process is sets of predicted primary and secondary ILT's.

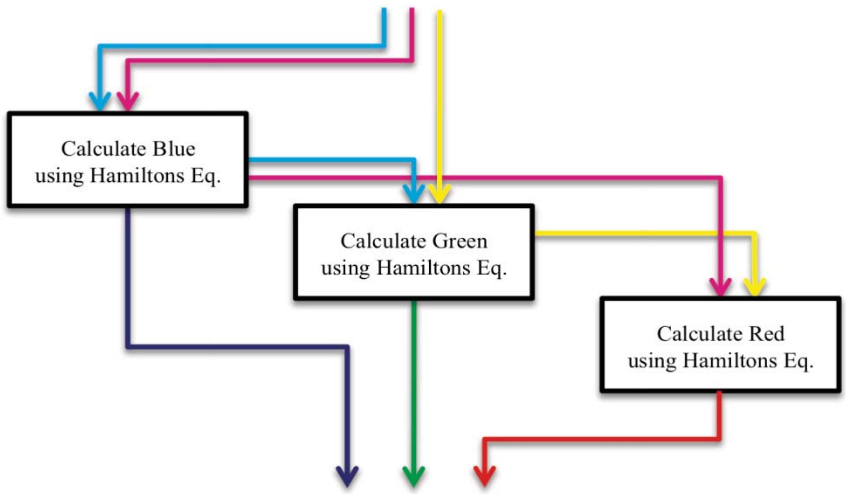

Figure 2: *Process #2 of the algorithm*

Process #3:

The last process in the algorithm is selecting the ink-sequence set of predicted ILT's that has the lowest ΔE_{ab} of the three two-color overprints. This is done by adding the three ΔE_{ab}'s of the two-color overprints and returning the entry that generates the lowest sum.

From the spectral reflection data, the density of the primary colors is calculated, and can then be used as aim points on the press.

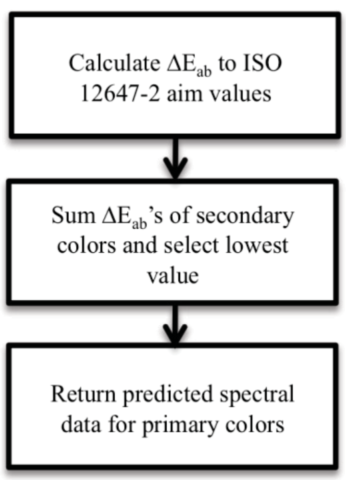

Figure 3: *Process #3 of the algorithm*

Part 2: Press run.

Setting up the printing press

It is almost impossible to only pull sheets from the press that conforms 100 percent to the needs for this research. The reason for this is the difficulty of controlling the ink levels on the press. To waste as little time as possible on the press, the press operator followed a procedure where two of the inks where stabilized and the third was altered from high to low across the sheet without stopping the press. This procedure was then repeated where a different primary ink was kept stable each time. This is a similar approach as printing a starvation test form, but that method is not sufficient for this research, where all possible combinations of two-color overprint is needed.

At the end of the press run, 197 different combinations of two-color overprints and the primary colors, at different ILT's, had been printed. The sheets was then organized and measured. To make sure that the necessary data was collected, measurements were made for all six colors (C, M, Y, R, G, B), which resulted in 1182 spectral reflectance data sets.

Figure 4: *Test form used in the press run*

The test form Figure 4 was printed on the Heidelberg Speedmaster 74 press at the Print Application Laboratory at RIT. The inks used for this experiment was ISO 2846 compliant and the paper was 80 pound coated text.

Validating inks and paper used in the press run

Since the goal of this research is to predict the combination of primary colors where the overprint of those, will result in the best conformance to ISO 12647-2, it is important that the measured values from the press run also conform to the standard. A method of visualizing this is to plot the density values of the inks compared with the ΔE_{ab} to the standard.

Another very important variable when talking about colors on a press is the color of the paper. The paper was measured 15 times on different sheets and then averaged to make sure that the result is a good representation of the actual paper color.

Part 3: Testing the algorithm

The spectral reflectance values of paper, primary and secondary colors were measured from high to low ILT. These measurements were then used as input to the algorithm. The best match to ISO 12647-2 (lowest sum of ΔE_{ab}'s), from the press run, will be used as the reference for the predicted values of the algorithm. The difference between the predicted colors and the best match from the press run, will give the accuracy of the algorithm.

Results

Press run

Validating inks and paper used in the press run

Figure 5 is a graph where density values on the X-axis and ΔEab to ISO 12647-2

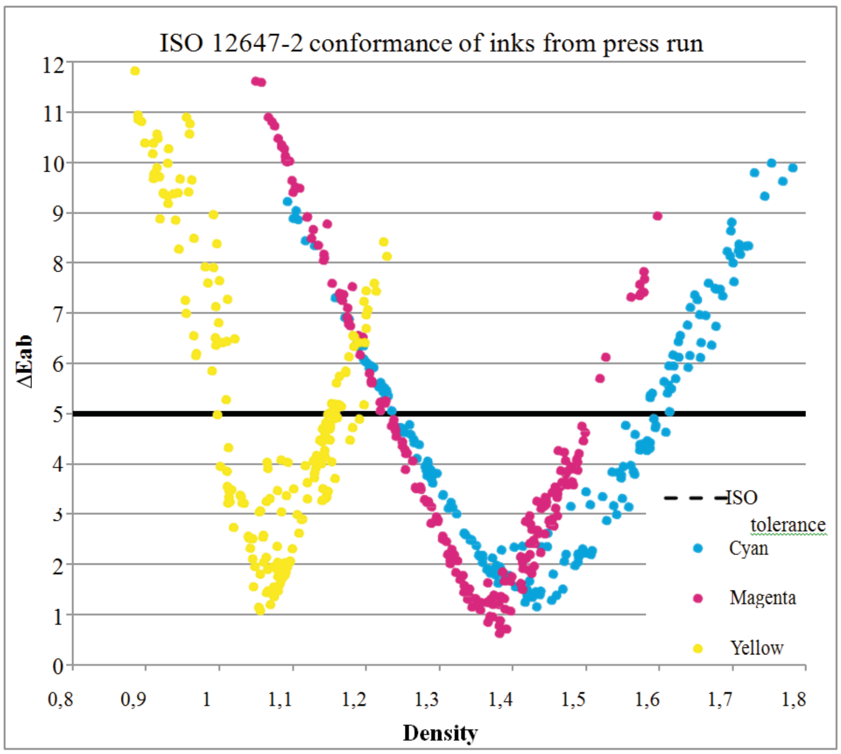

Figure 5: *Ink validation curves*

aim points on the Y-axis are plotted. The graph clearly shows that the inks conform to ISO 12647-2 and that they are well within the tolerances specified in ISO 12647-2 making them ideal to work with for this research.

Table 3 compares the ISO specified paper color for paper Type 1 gloss-coated, wood-free, and the average of the 15 measurements. The last row is the tolerances specified by ISO.

	L*	a*	b*
Paper type 1: gloss-coated, wood-free	93	0	-3
Average of measured paper	94	1	-2
Tolerances	±3	±2	±2

Table 3

The table shows that the paper conforms to the ISO 12647-2 specified color of a Type 1 paper.

Compiling measured data

The 1182 measured colors patches were organized into 197 data sets from the press run with spectral data from the colors: Cyan, Magenta, Yellow, Red, Green, and Blue. ΔE_{ab} to ISO 12647-2 was then calculated for all the colors and the ΔE_{ab} for both primary and secondary colors was summed in each data set to simulate the way that the algorithm computes the closest match to ISO of the overprint colors. The data set that gave the minimum sum of ΔE_{ab}'s was then chosen as the Best Match to ISO in this printing process.

# 29	Density	L*	a*	b*	ΔE_{ab}
Cyan	1.42	54.64	-35.39	-49.82	1.66
Magenta	1.32	49.04	72.36	-3.72	2.07
Yellow	1.12	87.93	-3.80	95.88	3.30
Sum of Primary Inks					7.03
Red		48.21	67.21	48.96	1.73
Green		46.80	-63.25	27.08	6.09
Blue		24.04	17.19	-45.54	0.50
Sum of Secondary Inks					**8.32**
Total					15.35

Table 4: *Best Match to ISO from press run*

Table 4 data shows set number 29, that has the best conformance to ISO aim points in terms of the sum of the overprint colors. This data set will be used as the reference data when testing the accuracy of the algorithm.

Performance of the algorithm (algorithm accuracy)

The algorithm was tested using all 197 data sets as input. Figure 6 is a Cumulative Relative Frequency curve that shows all the data sets and the predictions from the algorithm.

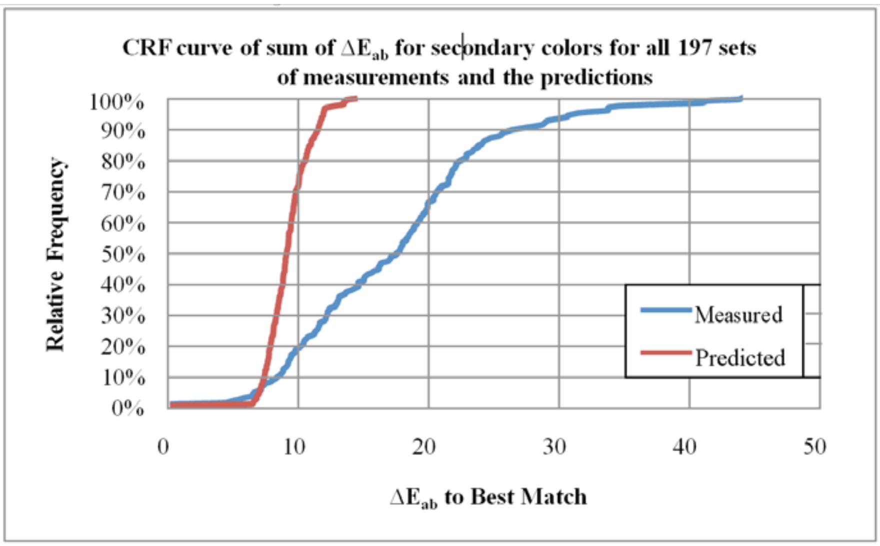

Figure 6: *Accuracy of the algorithm*

The steeper the curve is the more accurate the predictions are. The range between 0% and 90% is between a ΔE_{ab} of 6 and 11, which gives a maximum deviation of the algorithm of 5 ΔE_{ab}. It means that the accuracy of the algorithm is good. Then curve also shows that there is a problem with the precision of the algorithm. None of the predictions are less the 6 ΔE_{ab} to the Best Match data set. In 18 of the 197 computations the predictions are worse than the measured data. That can be seen where the two curves overlap in the 0 to 10% area of the graph.

Prediction errors

The data in Table 5 is a sample of all the measurements and predictions. The green row is the Best Match data, with ΔE_{ab} values to ISO 12647-2 aim points. The gray rows are the measurements and the white rows are the predicted data, both with ΔE_{ab} to the Best Match data set. The algorithm is trying to compute at what ILT will give the smallest sum of ΔE_{ab} from the secondary colors. In the secondary sum column of the table, one of the predictions (9.3) has a larger ΔE_{ab} value than the measured data (4.6).

		Cyan		Magenta		Yellow		Primary sum	Red	Green	Blue	Secondary sum	Total sum
#	**Type**	**Dens.**	**ΔE**	**Dens.**	**ΔE**	**Dens.**	**ΔE**	**ΔE**	**ΔE**	**ΔE**	**ΔE**	**ΔE**	**ΔE**
0	BM	1,42	1,7	1,32	2,1	1,12	3,3	7,0	1,7	6,1	0,5	8,3	15,4
1	Meas.	1,71	7,5	1,13	6,3	0,96	9,5	23,3	6,0	21,3	14,0	41,3	64,6
1	Pred.	1,35	1,7	1,47	4,2	1,10	1,8	7,7	2,9	8,0	3,6	14,5	22,2
10	Meas.	1,25	4,6	1,07	8,8	0,89	13,9	27,4	9,4	8,6	7,6	25,5	52,9
10	Pred.	1,45	0,5	1,38	1,8	1,02	5,5	7,9	1,5	4,0	4,9	10,5	18,3
20	Meas.	1,65	6,3	1,28	1,2	1,09	2,8	10,3	0,9	12,9	7,5	21,4	31,7
20	Pred.	1,40	1,8	1,41	2,8	1,12	1,1	5,6	2,0	5,3	3,2	10,5	16,2
30	Meas.	1,37	1,5	1,30	0,7	1,08	2,3	4,5	1,1	2,3	1,2	**4,6**	9,1
30	Pred.	1,49	1,2	1,41	2,7	1,07	2,8	6,6	1,7	2,5	5,0	**9,3**	15,9
60	Meas.	1,33	2,4	1,33	0,7	0,94	12,1	15,2	8,8	8,4	3,2	20,4	35,6
60	Pred.	1,50	1,3	1,39	2,4	1,12	2,9	6,6	1,5	2,7	3,8	8,1	14,7
90	Meas.	1,19	6,5	1,39	2,1	1,15	1,5	10,2	1,0	12,3	8,1	21,3	31,6
90	Pred.	1,53	1,9	1,39	2,1	1,11	0,7	4,7	2,0	3,0	6,0	11,0	15,8
120	Meas.	1,28	3,6	1,39	2,4	1,15	1,8	7,7	1,1	7,8	5,9	14,9	22,6
120	Pred.	1,54	2,2	1,39	2,4	1,11	1,0	5,5	1,6	2,1	5,6	9,3	14,8
150	Meas.	1,22	5,5	1,40	2,6	1,20	4,0	12,1	2,7	12,6	7,5	22,7	34,9
150	Pred.	1,54	1,8	1,38	2,2	1,11	1,4	5,4	1,7	2,4	5,5	9,6	15,1
175	Meas.	1,38	1,5	1,34	1,1	1,01	7,6	10,3	4,6	4,7	3,0	12,3	22,5
175	Pred.	1,55	2,3	1,42	3,2	1,07	4,5	10,0	1,5	2,4	4,9	8,8	18,8
197	Meas.	1,12	8,4	0,99	12,0	0,92	11,9	32,2	10,4	9,2	9,5	29,1	61,3
197	Pred.	1,48	1,2	1,36	1,5	1,01	6,1	8,8	1,5	3,7	5,5	10,8	19,6

The reason for these errors in the predictions is that there is some difference between the Best Match from the press run and the ISO 12647-2 aim points. This means that when the measured data is getting close to the ISO aim points the algorithm is still trying to optimize the predictions, even though it is not possible with these inks and paper.

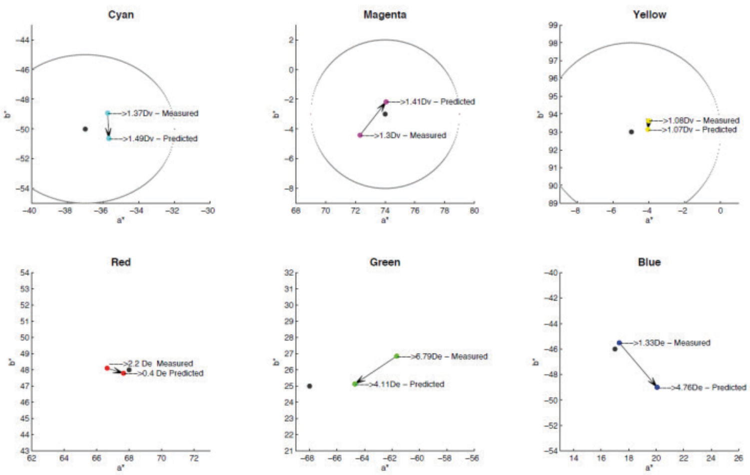

Figure 7: *Results of algorithm predictions on sample #30*

Figure 7 is sample number 30 shown in CIELAB color space, where the difference between the measured and predicted data is plotted. For the primary colors that it is the change in density and for the secondary colors it is the change in ΔE_{ab} to ISO 12647-2 aim point. ISO aim points are shown as black dots and the tolerances as a circle.

The figure shows that the algorithm is trying to optimize the data according to ISO specifications, but because the inks do not conform 100% to the standard, errors occurs. This is true for all the predictions where the sum of secondary colors in the measured data set is within a ΔE_{ab} of 8.

Using the algorithm for process control

Another way of looking at the predictions is to analyze the density values that will be used for process control on the press. The maximum, minimum, and range of all the 197 predictions can be seen in Table 6.

Measured Density	Cyan	Magenta	Yellow
Max.	1,78	1,60	1,23
Min.	1,09	0,99	0,88
Range.	0,69	0,61	0,34

Predicted Density	Cyan	Magenta	Yellow
Max.	1,56	1,48	1,18
Min.	1,35	1,30	0,99
Range.	0,21	0,18	0,20

Table 6: *Range of density values for measured and predicted data*

When comparing the density values from the measured data and the predictions, the algorithm did a very good job optimizing the result. The range of the predicted data is within what would be considered acceptable variations in daily print production. Comparing the range to John Seymour's conversion table from the literature review

(Table 2) shows that the range is well within acceptable variations. At this point it is also important to remember the first process of the algorithm (ref. methodology), where all predictions of the primary colors using Beer's Law have to be is within a ΔE_{ab} of 5.

Conclusion

This research investigates the possibility to predict the optimal ink layer thickness that generates the lowest ΔE_{ab} for the secondary colors aim values, while keeping primaries in conformance to ISO 12647-2.

It is possible to build an algorithm that uses Beer's Law to predict primary colors, and Hamilton's Trapping Equation to predict the secondary colors. The two equations combined, produces good results in terms of lowering the sum of the secondary colors. 95% of the predictions lowered the ΔE_{ab} of the secondary colors by more than half.

Because the inks used do not conform 100% to ISO 12647-2 aim points, the algorithm is trying to predict results that are not possible to produce with those inks. These errors in the predictions occur when the sum of secondary ΔE_{ab}'s between the measured data and the ISO standard is less than 8.

To optimize the algorithm further, the capabilities of the inks need to be known. Another method is using the Best Match data set as the reference in the algorithm instead of ISO aim points. The algorithm could be used to compute density tolerances as well.

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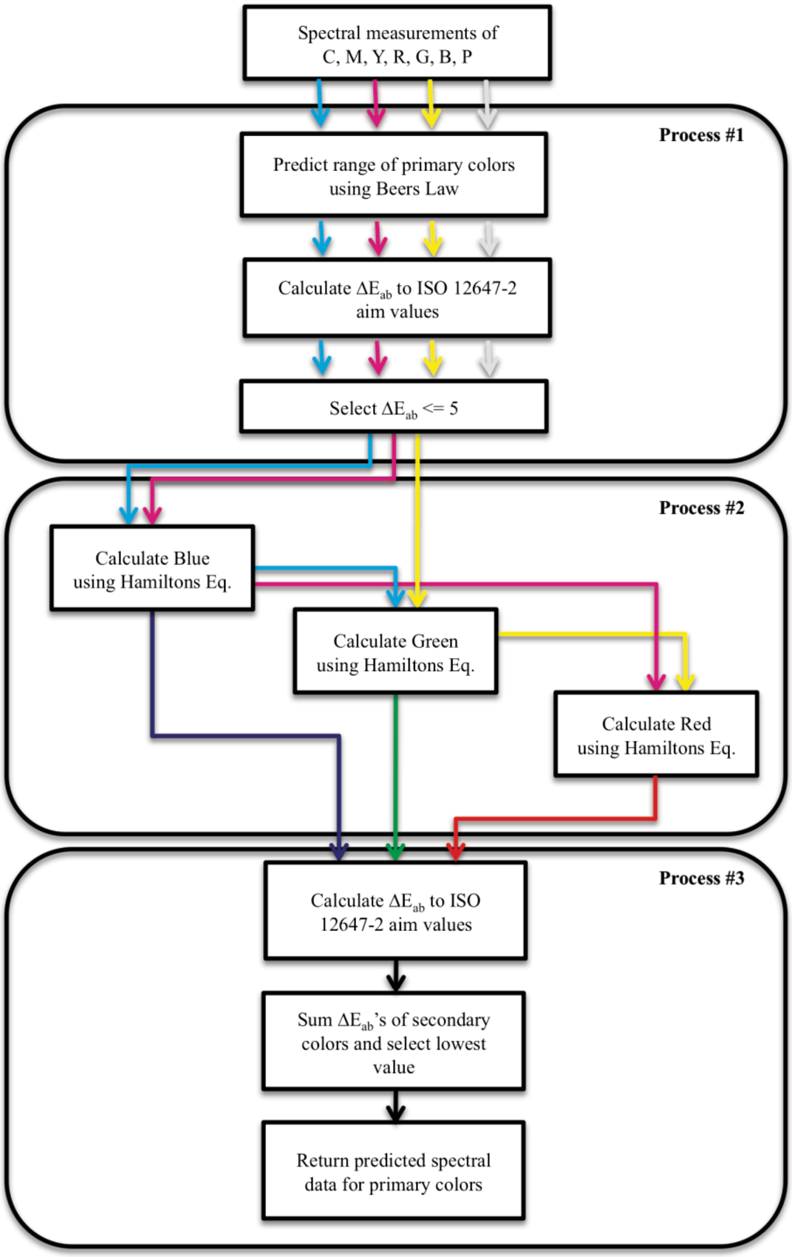
Appendix A



Flowchart of the algorithm