Reinventing the wheel: An attempt to create an objective technical color wheel for Pantone colors by using hue angles \((h_{ab})\) as the deciding factor

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Short Abstract

This study attempts to find an objective method to determine whether a given color is yellow, orange, or red, simply by evaluating its technical values and without looking at the color. After a review of the early Pantone Matching System and the current Pantone Formula Guide Coated, the first attempt to create a color wheel was to some extent possible. This was done firstly by selecting already named Pantone colors and colors that unambiguously belong to a particular color group, and secondly by using their hue angles \((h^*/h_{ab})\) to determine the boundaries surrounding the orange color group in the CIE \(a^*b^*\) projection circle. By this method, the orange color group is determined to be located between 41.5° and 85° \((h_{ab})\). However, more in-depth studies are required to verify or falsify this methodology.

Keywords: color wheels, Pantone, hue angles, color groups

1. Introduction and background

For years we have been able to determine whether a color difference is acceptable or not, simply by calculating the Delta-E values \((\Delta E_{ab} \text{ and } \Delta E_{00})\). In principle, it’s possible to evaluate color differences without looking at the colors. Likewise, it would be useful if it were possible to determine a color’s affiliation to a particular color group simply by looking at its objective values. For instance, is Pantone 116C yellow or orange?

In 2017, a study showed that it was possible to calculate the exact complementary color to a specific Brand Color (Pedersen 2017). This study will use the same form of practical trigonometry and calculation to determine the point at which a yellow color ceases to be yellow because it has changed into orange, and the point at which orange has changed into red. The assumption is that there must be a specific technical limit between these color groups.

It is not a new issue. Many others have tried to categorize colors and define boundaries between color groups.

As we all know, the wheel was invented approximately 300 years ago. In 1704 Newton published his seven-color wheel, in 1810 Goethe published his six-color wheel, and in 1905 Munsell published his 10-color wheel. What Newton’s, Goethe’s and Munsell’s color wheels had in common was that they all set clear boundaries between their hues or color groups.

During this 300-year period, many other color pioneers have contributed to color science with their versions of the color wheel. In the 1930s the CIELAB color system that we still use today was introduced, and in 1976 the CIE \(a^*b^*\) projection circle arrived (Billmeyer and Saltzman 2000). In the CIE \(a^*b^*\) projection circle, hue angles define four main color groups (red = 0°, yellow = 90°, green = 180° and blue = 270°).

In 2012, ISO TC-130 introduced hue angles as aim values for the ink solids CMY. As the only one of the eight process standards in the ISO 12647 series, ISO 12647-6:2012 defined aim values as CIELAB...
metric hue angles \((h_{ab})\). Thus, ISO TC130 defined cyan, magenta, and yellow color areas in the CIE \(a^*b^*\) projection circle, specified by hue angles. However, this process standard has now been withdrawn and a new version is under development.

In 2016 John Seymour defined those Pantone colors that unambiguously belong to a particular color group and plotted these areas into the CIE \(a^*b^*\) projection circle, e.g., orange color group: \(h^* 57–67\) \(C^* 67–96\) \(L^* 62–72\) (Seymour 2016). However, this included only a limited number of Pantone colors.

Many industries use their own color system and their own color wheel. The paint industry, architects and designers use the NCS color circle which is divided into 40 hues. The coatings and decorative industry uses the RAL Design color circle, which is divided into 36 hues and constructed to follow the CIE \(a^*b^*\) projection circle.

In the graphic arts industry, we primarily use the Pantone Color System, and the current Pantone Formula Guide is built upon 17 hues or basic colors. We also use the CIELAB color system for quality control.

However, the Pantone Color system doesn’t have an official color wheel to navigate from, and there seems to be no direct relationship between the CIELAB system and the Pantone system.

While existing color wheels (Newton, Goethe, Munsell, RAL, NCS) were created from the visual spectrum (on a scientific basis), around which a model was built, with colors determined and placed inside their models, a future Pantone color wheel will have to be built in the opposite manner. It is necessary to begin with existing physical color samples, after which a model can be built.

The reason for this is that Pantone is a practical color mixing system where physical printing inks are used to mix all of Pantone’s different colors. The Pantone colors already exist, but can they be placed systematically into a color circle?

This study will seek to create a Pantone color wheel that follows the CIE \(a^*b^*\) projection circle and sets clear boundaries between color groups. At the same time, it attempts to set clear rules for when a given color belongs to a specific color group, determined solely by its technical values.

2. Materials and Methods

In this study, the orange color group on coated paper is used as an example, after which the same systematics might be used to determine other boundaries between other color groups.

Two physical color sample catalogs have been used. Firstly, the Pantone Matching System, Printers Edition from 1973 (containing the same original colors and structure as the first edition, in 1963), and secondly the Pantone Formula Guide Coated, The Plus Series 2019.

These have been used to visually find specific colors, color order, and color group ranges. All colors were evaluated in a Largo Ortospectra viewing booth at 5000 Kelvin.

The Pantone CIELAB data from all 1,867 Pantone colors in the 2019 edition of Pantone Formula Guide Coated was downloaded from Pantone Color Manager software v.2.3.1.260 for Windows and stored in Excel. Hue angles \((h^*/h_{ab})\) and chroma values \((C^*)\) were applied using the formulas from ISO 13655:2009, section 5.3.2.

Although there most certainty are differences between Pantone colors from 1963, 1973, and 2019, it will not make any sense to measure a 46-year-old Pantone fan (PMS 1973). Therefore, all values for the 1973 edition were taken from Pantone’s digital 2019 version. For example, the CIELAB values for the old PMS 116 C (from 1973) are indicated with CIELAB values from 2019. The purpose of this study is not to investigate color differences from year to year.
No measurements have been made in this study.

3. Results and Discussions

Pantone has no official color wheel, such as Munsell, RAL or NCS. However, its website has a link to an unofficial color wheel from Before&AfterMagazine called “Our Color Wheel”. (https://www.pantone.com/downloads/articles/pdfs/BA0646OurColorWheel.pdf). Thus, Pantone must vouch for this color wheel. Nevertheless, it is unofficial and it is built in a illogical and non-technical way, showing the lightest tints (hue+white) in the center and the darkest shades (hue+black) at the outer edge. It seems that the Pantone lightness axis is placed where CIELAB shows chroma, and the Pantone chroma axis is placed where CIELAB shows lightness. Therefore, this wheel cannot be transferred to CIELAB.

Figure 1: Two versions of “Our Color Wheel” (Before&AfterMagazine). Left: divided into 12 hues/5 steps. Right: divided into 24 hues/7 steps. Added lines show orange areas of 90° placed differently.

Thus, it is necessary to return to the original Pantone catalog to analyze the underlying ideas behind the Pantone System. When Pantone published its color catalogue, Pantone Matching System, Printers Edition (PMS) in 1963, it contained 497 colors marked with three-digit reference numbers beginning with PANTONE 100 (yellow). The 497 colors were made by mixing some of the eight primary colors (basic colors), black, and transparent white.

According to Pantone, the colors were “arranged in chromatic format”, meaning that each page has seven colors where the middle color is the pure hue. Colors above are the pure hue mixed with transparent white (lighter), while colors below are the pure hue mixed with black (darker). This is probably the reason for the structure of Our Color Wheel.

The 1963 (1973) fan deck had 72 pages. Page 1 displayed the eight primary colors (basic colors). The following pages included seven colors each: one pure hue as the center color, three shades (hue+black) and three tints (hue+transparent white). Pantone called this “the center line concept”. The content was distributed as follows:

- 36 pages with 36 secondary colors (pure hues mixed by two primary colors) used as the centerline color;
- eight pages with eight primary colors used as the centerline color;
- seven pages with 49 different grays;
- 20 pages of 20 tertiary colors (mixed by three primary colors) used as centerline colors.

Thus, the original Pantone system had 44 pure hues (eight primary colors and 36 secondary colors).
In the traditional PMS fan deck, the three-digit Pantone numbers were numbered consecutively and arranged clockwise, largely following the CIE $a^*b^*$ projection circle, starting with yellow colors on the first pages, then orange colors, red colors, and so on, ending with the green colors (figure 2).

Figure 2: The 1963 (1973 edition) of the PMS color catalogue. Left: PMS page 1 showing the eight primary colors. Right: PMS page 9 showing a secondary color (151) as the centerline color.

Figure 3: PMS 1963 (1973) fan deck pages forming a CIE $a^*b^*$ projection circle. Centerline colors (secondary colors) are marked in between the bold circles. Axis for CIE $a^*$ and $b^*$ added.
By selecting the original 44 pure hues from the PMS centerline concept, a picture of a color wheel begins to be drawn. In figure 4 the eight primary colors and the 36 secondary colors forming the original PMS are plotted into the CIE $a^*b^*$ circle.

![Figure 4: PMS 1963 (1973) CIE $a^*b^*$ coordinates for eight primary colors and 36 secondary colors plotted into the CIE $a^*b^*$ circle. The orange color group seems to be between $h^*36.2$ - $h^*44.4$ and $h^*80.8$ - $h^*84.7$](image)

However, from 1987 Pantone added many new colors provided with four-digit numbers and inserted them chromatically in between the original colors. In addition, five new primary colors were added (Yellow 012, Orange 021, Red 032, Blue 072 and Violet) (pantone.com/pms-spot-color-information-formula-guides).

Since then, Pantone has added more and more colors each year, and has changed the paper from a yellowish paper to wood-free paper containing OBA. The 2019 edition of Pantone Formula Guide Coated now contains 1,867 colors mixed from the 17 basic colors, black, and transparent white. In figure 5 all 1,867 current colors are plotted into the CIE $a^*b^*$ projection diagram.
This color space spans from $L^* \text{ 7.9}$ to $92.1$ and from $C^* \text{ 0.2}$ to $110.9$. All $360$ hue angles ($h^*$) are represented when only whole rounded numbers are used. However, more than $1,800$ different hue angles ($h^*$) are represented when defined by two-digit decimals.

Therefore, it might be difficult to find one particular hue angle that separates two color groups. The first step could be to plot all $17$ primary colors and $90$ secondary colors from the $2019$ version of the Formula Guide (Figure 6).
An attempt to use a single page from the Pantone fan deck as a decisive factor gave a somewhat unexpected result. Due to the structure of each page in the Formula Guide, one might expect all seven colors from the same page to have approximately the same hue angle. But they do not, and there is a huge difference between the same color on coated and uncoated paper.

The color mixing from the same pure hue/ink (151 C&U) shows a span from $h^*52.2^\circ$ to $h^*71.1^\circ$ ($\Delta h_{ab}18.9$ and $\Delta H^*_{ab}18.7$). In general, the colors are much more reddish on uncoated paper (figure 7).
Figure 7: Seven Pantone colors from page 21C (circles), $h_{ab}$ from 58.9° to 71.1°($\Delta h*12.2$), and the corresponding seven colors from page 21U (triangles), $h_{ab}$ from 52.2° to 63.5°($\Delta h*11.3$).

Therefore, it is not possible to use one page in the Pantone fan deck as the defining factor. It is necessary to look at some of the secondary and tertiary colors that appear to be placed on the borders between color groups.

In the Pantone Formula Guide some of the colors are already named Red, Orange, Yellow, etc. Pantone Orange 021C has a hue angle ($h_{ab}$) of 52.3°. In the same Pantone Formula Guide other colors can clearly be identified as being orange, light orange, or dark orange. For instance: 123C ($h*$80.8), 130C ($h*$75), 137C ($h*$69), 7548 ($h*$82.9), 141C ($h*$81.5), 144C ($h*$65), 151C ($h*$59), 158C ($h*$55), 165C ($h*$49), 171C ($h*$41.7), and 172C ($h*$44.4). This is a span from 41.7° to 82.9°.

Moving onward in the numbered pages of the Formula Guide, the first colors named red (and so not orange) are Warm Red C ($h*$36), Red 032C ($h*$31) and Bright Red C ($h*$40.4). Other clearly red colors close to orange are 485C ($h*$38), 486C ($h*$37.5), 185C ($h*$32.5), 186C ($h*$30.6), and 2347C ($h*$41.2).

Therefore, the border between red and orange seems to be placed between 41.2° (red 2347C) and 41.7° (reddish orange 171C). It will be simple to assume that the limit is $h_{ab}$ 41.5°.
At the other end of the orange area, moving upwards to yellow, Pantone Yellow C has a hue angle of 90.7° and Pantone Yellow 012C has a hue angle of 88.9°.

Other colors close to orange can clearly be identified as being yellow. For instance: 113C (h*91.1), 104C (h*90.2), 106C (h*93.2), 114C (h*90.1), 108C (h*89.6), and 115C (h*88.9). The lowest hue angle in this part of the yellow group is 88.9° (Yellow 012C).

On the next pages, Pantone 109C (h*86.5) and 116C (h*84.7) seem to be a more reddish yellow and thus appear to be on the border between yellow and orange. The clearly orange 130C (h*75) is placed on page 7, and on page 9, Pantone 122C (h*84.5) and 123C (h*80.8) appear to be more orange than 109C (h*86.5) and 116C (h*84.7).

It might seem that the limit between yellow and orange is found between the reddish yellow 109C (h*86.5) and the light yellowish orange 122C (h*84.5), presumably at $h_{ab} 85°$.

As one of the consequences, Pantone 116C (h*84.7) is included in the orange color group. Figure 8 shows all the mentioned colors.
Although this approach contains some uncertainties, the orange color group for Pantone C can be defined as lying between 41.5° and 85° in the CIE $a^*b^*$ projection circle.

By sorting all 1,867 Pantone colors by hue angle in Excel, it was possible to find the orange color group consisting of 342 Pantone C colors (figure 9).

3.1 Preliminary Results
Setting a limit of $C_{ab} > 15$ and another limit of $L^* > 30$ excludes 57 colors, including black, gray, and some of the colors in the darkest area, leaving 285 colors for the orange area (figure 10).
Figure 10: 285 colors in the orange color group, defined by $h^* \in [41.5, 85]$, $C^* > 15$ and $L^* > 30$. Left: illustrated in a CIELAB $a^* b^*$ diagram. Right: illustrated in “3D” showing Lightness.

Figure 11: Orange color group in a CIELAB Chroma versus Lightness diagram

The first preliminary sketches for a Pantone color wheel are shown in figure 12 and 13.
Figure 12: Preliminary rough sketch for a future Pantone Coated color wheel.

Figure 13: Estimated preliminary sketch for a future Pantone Coated color wheel.
4. Conclusions

The first step in creating a color wheel for Pantone colors has to some extent been possible by setting up three technical criteria:

\[ \text{Pantone Coated; orange color group } = h_{ab} 41.50–85.00, \ C_{ab} > 15.00 \text{ and } L^* > 30.00 \]

Thus, if a Pantone Coated color meets these criteria, it is orange. However, this results in very narrow and sharp borders between color groups. Decimals determine whether a color belongs to the orange or red color group. This does not seem to be ideal and might be too uncertain.

Thus, it might be necessary to set up other criteria and to analyze many more Pantone colors to determine all the main Pantone color groups in the CIE $a^*b^*$ projection circle (yellow, green, blue, violet, purple, and red). It is also obvious that each substrate type must have its own color wheel and criteria.

References


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