An Investigation of Color Management Applications For Nonwoven Materials

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Abstract
Procter and Gamble is currently investigating technologies to improve their color management capabilities for various business applications. It is essential for a proper color management workflow to exist to ensure that the different visuals on products adhere to a high standard of quality. Initial findings revealed that conventional color management procedures lacked the ability to properly measure color on the nontraditional nonwoven substrates used by Baby Care. The following document summarizes the research done to investigate these particular issues and their proposed solutions.
An Investigation of Color Management Applications
For Nonwoven Materials
Dan Shi
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Procter and Gamble is currently investigating technologies to improve their color management capabilities for various business applications. It is essential for a proper color management workflow to exist to ensure that the different visuals on products adhere to a high standard of quality. A key component of the standard workflow must include an efficient measurement capability. Initial findings revealed that the conventional color management procedures lacked the ability to properly measure color on the nonwoven substrates used by Baby Care. An investigation was conducted to identify the fundamental problem with the measurement difficulties. It was discovered that the equipment being used was not designed to measure color on the low base weight materials that exhibited translucent characteristics. In conclusion to the research, it was proposed to make an adjustment to the initial workflow by utilizing a different spectrophotometer that was better suited for Baby Care needs.
I. Introduction

Procter and Gamble Baby Care Process and Engineering is currently investigating color management technologies for key business applications. Color management is a vital component of any color producing system (i.e. digital photography, label printing etc.). Proper management ensures that any given image is experienced consistently across different forms of medium. More formally, the technical definition of color management is “the controlled conversion between the color representations of different devices.”[1] A wide range of factors influence how color is managed such as the means to display a particular visual and the conditions that the visual is being observed under. It is important for P&G to have a reliable and efficient management workflow that satisfies their particular business needs. The particular objectives of this project were to evaluate current color management capabilities, investigate their ability to handle proposed business initiatives and finally provide long term solutions and guidance based off key findings.

It is important to have a background of color theory as a basis to better understand the process of managing color. There exists many differences between how the human eye and instruments “see” color. The human eye processes visible light radiation reflected off of different surfaces by using various stimuli that behave like monochromatic filters to measure the intensity of red, green and blue wavelength of any given light wave. The brain then interprets the varying combination of red, green and blue light to form the colors we can see in the visible light spectrum. Spectrophotometers operate differently by analyzing the entire wavelength and conduct a spectral analysis to identify where particular light waves have the most intensity to extrapolate the specific color reading [1]. The means of which an instrument processes
wavelength data is minor when compared to the importance of how the light is actually collected by the given device.

The human brain is able to differentiate many complicated factors when “seeing” color such as depth and saturation. Instrumentation must be engineered specially to handle all of the subtle characteristics that influence the “appearance” of color. Many factors, which are described in depth throughout the paper, make the measurement of color very difficult and complex. For example, spectrophotometers collect light measurements in many ways to try and compensate for as many of these factors as possible. The i1Pro 2 and SpectroEye spectrophotometers used at P&G utilize a 45°/0° measuring geometry which means that the sample being measured is illuminated via a light source at a 45 degree angle normal to the surface and measured at the normal. This configuration can be seen in Figure 1. The 45°/0° measuring geometry is very common among spectrophotometers due to its ability to replicate how light behaves when making contact with most opaque surfaces. The substrates used at P&G exhibit translucent characteristics which makes the 45°/0° measurement geometry useless due to the inability to account for the effects of scattered and diffused light. The complexity of color measurement was investigated to find a more efficient measurement method for color management at P&G.

II. Methodology

The i1Profiler software used for color management at Procter and Gamble is accompanied by a measurement system that includes the i1i0 2 automated table and i1Pro 2 spectrophotometer. When used to create printer profiles, i1Profiler is most efficient to improve high quality systems (i.e. digital photography) that utilize conventional substrates [1]. The software and equipment can be used to effectively profile printing on the other substrates with a
few changes to maintain performance. A thorough evaluation of the equipment’s capabilities was made to understand which modifications need to be made to maintain a high performing system.

a. Equipment Evaluation

The primary spectrophotometer used was the i1Pro 2. This device is one of the most reputable in industry and consumer markets for printer profiling. Printer profiling requires the color measurement of up to thousands of color patches on numerous test charts. Pairing the i1Pro 2 device with an i1i0 2 automated measuring table allows for time efficient color measurements. These color patches are traditionally organized as rows and columns on multiple tables. The system relies on three different measurement modes: Single Scan, Dual Scan and Single Spot Scan. The measurement mode used for each row depends on its readability. The first scan of any row will be a Single Scan where the entire row is measured in a single pass from one end to the other. The device will scan the row again resulting in a Dual Scan if the device experiences difficulty retrieving quality measurements. If the second measurement attempt fails, the device will then rely on a Single Spot Scan where the device will measure each patch individually, take multiple measurements and average the result.

The equipment system was evaluated by first measuring test charts on traditional substrates such as copy paper. The spectrophotometer collected accurate color measurements which were double checked with another hand held X-Rite SpectroEye spectrophotometer. The equipment had difficulty collecting measurement data and resulted in system failure once test charts on translucent nonwoven substrates were measured. The system failure refers to the automated table frequently re-measuring the same color patch while still returning inconsistent data. This was discovered by repeating the measurements with a handheld spectrophotometer and re-measuring the entire test chart with the automated i1i0 2. This anomaly in scanning
behavior was analyzed. The issues were eventually attributed to the unique substrate characteristics that the i1Pro 2 spectrophotometer was not designed to account for.

b. Impact of Translucent Properties

The particular substrate characteristics that prevented proper data acquisition via the i1Pro 2 spectrophotometer were identified to be due to its physical inconsistency and translucency. These conclusions were made by using the SpectroEye spectrophotometer to observe the deltaE fluctuations across common color patches. A standard tolerance for deltaE was formed by measuring the color patches on traditional copy paper and accounting for the sensitivity of human eyes to detect deltaE fluctuations. DeltaE is a standard metric for color difference. The value represents the Euclidean distance in a device independent color space which encapsulates the colors in the visible light spectrum as a three dimensional space. Note: The Lab color space, which can be seen in Figure 3 and discussed further in section III.c., was the standard device independent color space used throughout the research.

III. Results and Discussion

a. Equipment Evaluation

The i1i0 2 behavior was analyzed and yielded two important results, the frequency of measuring modes across different substrates and the average time to measure test charts. Table 1 shows the frequency of measurement modes across the different substrates. It is apparent that the measurement of the landing and zone and top sheet materials are similar where they share ~30% single scans and more than 50% spot scans. The reference to different elements of the diaper can be seen in Figure 4. This behavior is not found with the paper and fastening tape which share ~60% single scans and less than 30% spot scans. The large time measurement differentiation between substrates contributed to the first indication that the lack of proper measurement were
due to substrate characteristics. The spectrophotometer would also behave inconsistently by measuring some patches multiple times and others quickly.

b. Impact of Translucent Properties

The initial observations revealed that the equipment indeed worked properly but was specifically designed to be used with opaque surfaces. The measurement challenges for the nonwoven material was attributed to its translucency. A follow up study was conducted to verify the findings by gathering opacity measurements and deltaE variations for measuring any given color patch multiple times. These color patches were strategically chosen to reflect the common colors found in current market visuals, future visuals and as well as those that covered the largest region of the LAB color space. The data set of color patches across each substrates was around fifty. It would be ideal that there exist a correlation between the opacity measurements and deltaE variations to support the notion that the translucent characteristics were indeed the cause of measurement issues. The opacity measurements shown in Table 2 revealed that the fastening tape and copy paper had higher opacity due to their higher base weight while the landing zone and top sheet had lower opacity. Although other factors such as the thermal bonding patterns can cause inconsistent measurements, the combined correlation between the opacity and deltaE fluctuations seen in Table 3 support the notion that the translucent properties caused a higher deltaE variation.

Disclaimer: The high deltaE variations for the landing zone is attributed to thermal bonding patterns that are not seen on the top sheet. These physical characteristics indeed compromise the measurement process but due to the proprietary elements of the particular substrate further evaluation results are being withheld from this research paper.

c. Color Theory Investigation
Potential solutions were investigated by understanding how color is perceived and measured. The objective of measuring colors is to describe a colors “appearance” and representing it in a standard way such as a number. It is standard to describe color in a particular color space such as RGB, CYMK or CIELAB. RGB (for red, green, blue) and CMYK (for cyan, magenta, yellow and black) are device dependent color spaces which means that devices will interpret the same color differently and associate a different RGB or CMYK value depending on that particular device. An easy way to think about this is that two separate display screens will produce a color such as red differently depending on that device’s specific internal configuration. RGB is also a subtractive color space which means that light is taken away from a black background to create a visual. This color space is seen in display screens. CMYK is an additive color space which adds a combination of cyan, magenta, yellow and black material to a white background to create different colors. The LAB color space is a device independent color space that is used when converting from device dependent color spaces. A good example of this is when a digital photographer captures an image which is stored with embedded RGB values. When the image is ready to print a conversion must be made to CMYK via a device independent color space. These color conversions are an example of how color management is used to effectively create a desired output, whatever that may be.

A particular value in a color space does not appropriately describe the colors appearance since it may change under different illumination and observer conditions. During measurement, the illumination of samples are set under a constant condition determined by the International Commission on Illumination (CIE) and can be changed for different circumstances via i1Profiler. The illumination of surfaces due to natural and artificial light sources can be measured using a measurement tool such as a spectrophotometer. Illumination is measured based on their
correlated color temperature, or the temperature of the Planckian radiator. For example the temperature of daylight is 6,500 Kelvin while fluorescent lamps are 5,000 Kelvin. The observer conditions are dictated by these illumination characteristics. Lighting booths that are used to evaluate color by human perception have a standard lighting condition set to keep the environmental light consistent.

The complexity of measuring color is resolved by trying to take into account as many factors as possible. This is often easier for certain substrates that are opaque but harder for translucent materials that are not known for their color consistency. Special handling procedures must exist to make sure that the color is being evaluated properly. The color of translucent substrates are particularly vulnerable to a varying path length. The light used to illuminate the substrate will also be diffused and scattered in ways that an opaque substrate would not generally experience. Standard ambient light and standard background conditions must be in place to account for these changing elements [2].

The three most important factors of measuring color are the light source, sample being measured and the observation conditions. Different light sources have different light intensities and create different illumination of the sample. The composition of the sample is important since it directly influences the absorption, transmission, and reflection of the light from the source. The different light waves that are being reflected and/or transmitted light are influenced by the sample so it is important to have correct observer conditions [1].

These three major factors are taken into account differently depending on the measuring geometry. The most common are the 0°/45° and 45°/0° geometries found on board the i1Pro 2 and SpectroEye spectrophotometers. This specific geometry lacks the ability to measure translucent substrates due to the structural variations. A geometry with diffuse illumination or
observation can be used to compensate for the variations. Standard geometries that use diffuse illumination or observation are the 0°/d and d/0°. The “d” stands for observation and illumination of the light that is diffusely scattered by the sample by means of the wall of an integrating sphere [3]. The two different geometries can be seen in Figure 1 and Figure 2.

IV. Summary and Conclusions

The research findings verified that although the equipment worked well, they were not designed for the specific color management workflow that was being investigated by Procter and Gamble. The inability to properly to measure the color on translucent substrates compromised the ability to manage color across the nonwoven products. The recommendation was to find a spectrophotometer better suited for the situation. Many spectrophotometers could accurately measure the color of an unconventional substrate but due to the limited market for color management operations on non-opaque surfaces, there exists very few spectrophotometers designed to be compatible with standard color management software. The search for a device marketed towards color management operations was found in the Barbieri Spectro LFP. This device’s form factor is very similar to the i1i0 2 and i1Pro 2 configuration but also features the capability to measure transmission data via the d/0° measurement geometry. Procter and Gamble is currently investigating the potential applications of the Barbieri Spectro LFP with their business needs at this time.
References


Table 1. Compares different i1i0 2 measurement behavior across different substrates. The differences are attributed to the differences in physical characteristics. A single scan is ideal and most efficient while spot is most time consuming and used when single and a repeated dual scan are inadequate to collect sufficient data.

<table>
<thead>
<tr>
<th></th>
<th>Paper</th>
<th>Fastening Tape</th>
<th>Top Sheet</th>
<th>Landing Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single</td>
<td>61%</td>
<td>55%</td>
<td>33%</td>
<td>26%</td>
</tr>
<tr>
<td>Dual</td>
<td>22%</td>
<td>15%</td>
<td>17%</td>
<td>10%</td>
</tr>
<tr>
<td>Spot</td>
<td>17%</td>
<td>30%</td>
<td>50%</td>
<td>64%</td>
</tr>
</tbody>
</table>
Table 2. Provides a comparison of the opacity of the different nonwoven substrates being studied. The data reveals and supports the notion that some substrates exhibit more translucent characteristics than others. This data can be correlated with information shown in Table 1 which implies that the translucent properties create difficult measurement conditions.

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Opacity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 gsm Top Sheet</td>
<td>13.4%</td>
</tr>
<tr>
<td>25 gsm Landing Zone PP</td>
<td>16.5%</td>
</tr>
<tr>
<td>80 gsm Fastening Tape</td>
<td>59.8%</td>
</tr>
<tr>
<td>Copy Paper</td>
<td>86.0%</td>
</tr>
</tbody>
</table>
Table 3. The table shows the average deltaE variations while measuring a combination of different color patches across different nonwoven substrates. The larger deltaE variations associated to the lower base weight materials imply that the translucency and low base weight characteristics create issues with the current measurement methods. The thermal bonding patterns across the landing zone contribute significantly to the higher deltaE variations. These elements are not discussed due to scientific embargo. Note: It is widely accepted that the human eye can differentiate colors that have approximately a deltaE of three, changing depending on the particular color. Humans can see differences in some colors better than others.
Figure 1. Displays the 0/45 and 45/0 measurement geometries respectively. These geometries are used for “reflective” measurement on opaque surfaces. They are the most commonly seen in spectrophotometers such as the i1Pro 2 used throughout the research done at Procter and Gamble.
Figure 2. Displays the 0/d and d/0 measurement geometries respectively. These geometries are used for “transmittance” measurement. These geometries are most commonly seen in spectrophotometers such as the Barbieri Spectro LFP, the recommended spectrophotometer to be used with substrates that are translucent in nature.
Figure 3. Shows a visualization of the LAB color space which was first created by the International Commission on Illumination in 1976. It encapsulates all of the colors that exist in the visible light spectrum.
Figure 4. Shows the anatomy of a Pampers diaper.

*Represents currently marketed Pampers® diapers sold in mass market retail outlets only.