Escola Tècnica Superior d'Enginyeria de Telecomunicació de Barcelona

UNIVERSITAT POLITÈCNICA DE CATALUNYA

PROJECTE FINAL DE CARRERA

Automatic media identification

Estudis: Enginyeria de Telecomunicació

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Any: 2011

Quiero dedicar este proyecto a toda la gente que me ha apoyado día a día hasta alcanzar esta meta. Especialmente a mi familia que siempre a confiado en mí y que me ha brindado todos los medios necesarios para que llegara este momento. Como no, dedico este proyecto a Gemma, la persona con quien he compartido mi vida y con quien realizaré mis nuevos proyectos de futuro.

También quiero dedicar este proyecto a mis amigos de la universidad. Ellos son sin duda lo mejor que he encontrado en la carrera. Es para mí toda una satisfacción que sigamos viéndonos pese al tiempo que hace que acabamos y a las distancias que nos separan.

Me gustaría también agradecer a mis compañeros de trabajo Aleix Oriol, Jacint Humet, Johan Lammens, Mikel Zuza y Óscar Martínez sus consejos sobre el proyecto y sobre el trabajo del día a día.

Por último y no por eso menos importante agradecer a Rosa Ma. Fernández todos los ánimos que me ha dado, toda su buena disposició y la ayuda que me ha prestado.

Por todo esto y más, gracias a todos.

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COLABORATIONS

This project has been developed in Hewlett-Packard R&D Lab in Sant Cugat del Vallès.

This project has been done in collaboration with the TSC Teoria del Senyal i Comunicacions department from the UPC Universitat Politècnica de Catalunya.

RESUMEN DEL PROYECTO

Este es un proyecto multidisciplinario que ha sido desarrollado en los laboratorios de RiD de Hewlett-Packard (HP) de Sant Cugat del Vallés. La propuesta de proyecto vino del grupo de Color&Pipeline sobre tres años atrás y se acordó desarrollarla como una beca. Su objetivo era encontrar una técnica que identificara automáticamente el tipo de papel del rollo cargado para configurar la impresora con los ajustes customizados del papel para conseguir la máxima calidad de impresión y la reproducción de color más precisa.

A lo largo del proyecto se justificará la razón de utilizar ajustes de papel y la necesidad del proceso de identificación automática y el valor añadido para el usuario final. Se presentarán varias propiedades físicas de los papeles, las técnicas disponibles para medirlas con sus aparatos de medida junto a la gama de productos de papel de HP. También se explicaran a fondo los aparatos de medición utilizados, espectrofotómetro y glosímetro y los retos de integración para insertarlos dentro de la impresora.

Finalmente, basado en las medidas espectrales y de gloss de la superficie del papel se han realizado una serie de análisis estadísticos siguiendo la metodología Six Sigma. Para hacer dichos análisis se han utilizado programas especializados de cálculo como MiniTab R14 o MATLAB R2010a. Para concluir, se ha propuesto un flujo de análisis que combina las diferentes técnicas para finalmente lograr la identificación automática.

Como resultado de este trabajo se propondrán una serie de sugerencias para bajar el precio del hardware necesario para utilizar este método a la vez que aumenta la fiabilidad y la tasa de aciertos del método, haciendo posible su comercialización tanto en el segmento de impresoras técnicas como en de impresoras de bajo coste.

Los resultados de este trabajo de investigación se resumieron en un paper que se presentó al congreso HPICS HP Imaging and Color Symposium donde fue aceptado para presentar en formato poster. Tanto el paper como el poster están incluidos en el apéndice al final de este libro.

RESUM DEL PROJECTE

Aquest es un projecte multidisciplinari que ha estat desenvolupat als laboratoris de RiD de Hewlett-Packard (HP) de Sant Cugat del Vallès. La proposta de projecte va vindre del grup de Color&Pipeline i es va acordar desenvolupar-la com a una beca. El seu objectiu era trovar una técnica que identifiqués automàticament el tipus de paper del rollo carregat per a configurar la impressora amb els ajustos customitzats del paper.per a conseguir la màxima qualitat d'impressió i la reproducció de colors més precisa.

Al llarg del projecte es justificara la raó de fer servir ajustos de paper i la necessitat del procés d'idenificació automàtic i el valor afegit per a l'usuari final. Es presentaran vàries propietats físiques dels papers, les tècniques disponibles per mesurar-les amb els seus aparells de mesura junt a la gama de productes de paper d'HP. També s'explicaran a fons els aparells de mesurar que s'han fet servir, espectrofotòmetre i el glosímetre i els reptes d'integració per inserir-los dins la impressora.

Finalment, basats en les mesures espectrals i de gloss de la superfície del paper s'han realitzat una sèrie d'anàlisis estadístics seguint la metodologia Six Sigma. Per fer aquests anàlisis s'han fet servir programes especialitzats de càlcul com MiniTab R14 o MATLAB R2010a. Per concloure, s'ha proposat un fluxe d'anàlisis que combina les diferents tècniques fer a finalment aconseguir l'identificació automàtica.

Com a resultat d'aquest treball es proposaran una sèrie de suggerències per abaixar el preu del hardware necessari per fer servir aquest mètode a la vegaga que augmenta la fiabilitat i la taxa d'encerts del mètode, fent possible la seva comercialització tan en el segment d'impressores tècniques com en el d'impressores de baix cost.

Els resultats d'aquest treball d'investigació s'han resumit en un paper que es va presentar al congrés HPICS HP Imaging and Color Symposium on va ser acceptat per presentar-lo enformat poster. Tant el paper com el poster estan inclosos a l'apèndix al final d'aquest llibre.

ABSTRACT

This is a multidisciplinary project that has been developed in Hewlett-Packard (HP) R&D Lab facilities in Sant Cugat. The project proposal came from the Color&Pipeline group about three years ago and it was agreed to develop it as an internship. Its objective was to find a technique to automatically identify the media type of loaded roll to set-up the printer with the custom paper presets to achieve the maximum image quality and the most accurate color reproduction.

Along the project it will be justify the reason to use paper presets and the need of the automatic identification process and the value added for the end user. It will be introduced a many different paper physical properties, the available techniques to measure them with its measurement devices with the HP media portfolio. It will also be deeply explained the used measuring devices, the spectrophotometer and the gloss meter and its integration challenges to put them inside a printer.

Finally, based on the spectral and gloss measurements from the paper surface it have been performed a set of statistical analysis following the six sigma methodology. In order to do them it has been used specialized software as Minitab R14 and MATLAB R2010a. To conclude, it has been proposed a workflow that combines these different techniques to achieve the final automatic identification.

As a result of this entire job a series of suggestion are proposed to lower the price of the hardware necessary to use this method while increasing the reliability and success rate of the method, making possible to commercialize it both in the low-end and in the technical print segment.

These research work results were summarized in a paper that was presented to the HPICS HP Imaging and Color Symposium congress where it was accepted as a poster presentation. Both the paper and the poster are included in the Appendix at the end of this book.

1. INTRODUCTION

1.1 MOTIVATION

The amusing world of paper dates back to early ages. It has been a long time since those antique Egyptian papyruses that were made by weaving papyrus plant fibers that gives them their name, which is the origin of the word “paper”. Nowadays, the paper industry keeps on expanding supported by consumption. However, industry has specialized according to the final usage of the paper. So, currently, there are an infinite number of classes and categories of paper. As an example, I can mention, standard paper for documents, packaging paper, domestic paper… According to the intended use, some characteristics are preferred over others. For example, on the one hand we have packaging paper where we try to enhance the resistance that it is able to offer us while its typical brownish colour shade is accepted as something normal in its class. On the other hand, we can find office paper where its whiteness level and its grammage[1] is appreciated. Another different case is the domestic paper that we all use in ours kitchens. In this case, we prefer maximum absorbance and it is typically decorated with homey motifs and we do not care about its whiteness.

However, in this document we will focus on the aspects in which industry and graphic-arts interests converge, where we can find an extensive media set to reproduce works of art made by art-designers, painters, and artists in general. Therefore the market provides photographic paper for photographers, outdoor paper for banners, used by advertising agencies or canvases for painters or painting reproduction.

This project was born from this specialised market that has wanted an easy-to-use solution to do this classification automatically.

The main goal for this project is the differentiation and classification of the different printing media attending to objective and quantifiable characteristics, grouping them by families and categories. The identification process will not be destructive. To perform it we have a spectrophotometer and a gloss meter. Both of them, forced by specifications, are not the most appropriate to characterize the papers to classify because there is no strong correlation

[1] Weight in grams of a quantity of paper cut to sheets that measure one square meter.

between the measured magnitude and the performance that the paper offers us. This is why this project is placed in an investigation framework since suitable characteristics to analyse, classification patterns to follow up and finally the strategy to get the result, has to be found.

1.2. OBJECTIVES

This project will be organized in three blocks that we can identify as differentiated objectives. The achievement of each of them will provide us with a functional tool to reach the final goal of this study and that consists in the ability to distinguish and identify to which group each paper pertains, maintaining an error probability lower than one per cent.

1. The first stage comprises the **design of the experiment** that will provide the data for a database which we will work with later. The parameters that should be measured, how to obtain and process them and how to organize those measures in the database will be the tasks tackled trough this block. Finally the database will contain the measures from the different papers to analyze and the conditions in which they were taken.

2. In a second stage, we will **investigate spectral and gloss paper properties** and its relevance, thinking in a future classification. A justification will also be included on the results obtained from the measures correlating them with physical properties of the paper. This is without any doubt the darkest area due to the measurement instruments used are not thought for this goal. Furthermore, it has never before been tried to classify papers automatically by their spectral appearance, inside HP.

3. Finally, by studying these measures, behaviour patterns of each paper will be obtained and will allow us to state a set of rules to do this **classification into their families**.

As we have mentioned before, meeting these three objectives will be necessary to reach the goal proposed in this project that is to allow an inexpert-user to choose automatically, which is the family group of each paper with the same confidence that an expert user would have.

1.3. SCENARIO

Nowadays, we find it relatively easy to make a distinction between the different media families using their appearance as their main characteristic. It is expected that anybody has to be able to distinguish which paper to use for maps and which one for photographs. Even though, there are families that are not as easy to differentiate them to such an extent that they are confused quite often. As an example, paper used in magazines, have the characteristic glossy appearance that photographs have. People differentiate it easily by its thickness (grammage), but what about if it is not allowed to touch the batch? Furthermore there are other cases in which papers that belong to the same family have different categories, which make things more difficult for buyers. Taking office paper as an example we have an extended variety that depending on its category is more or less white, with more or less grammage and with different variations of these two factors. However, buyers are only able to distinguish the extreme cases (draft paper or paper for presentations), with a large number of them classified in the same category.

This project has been boosted by the necessity of an automatic method of paper classification according to their characteristics. At the same time, it has to be reliable and need to have more resolution and accuracy than a standard user. For that purpose we will have a spectrophotometer, a gloss meter and a vast amount of creativity!

1.4. ABOUT THIS DOCUMENT

This document intends to be a general study about graphic-art paper properties. It is expected to be considered as a reference on this field for later investigations that can extract their own benefit from this text.

This project has been in the research and development department in an important enterprise that works in this sector. All the testing materials, measurement instruments, computing solutions and research resources, have been provided by them.

As it is normal in these situations, due to confidentiality clauses, neither the final implemented algorithm nor the complete results, will be published. At any rate, it remains as a free option to the reader to develop and implement his own technique. Thus, a complete investigation can be expected from this document about the characteristics that the different kinds of papers have, a complete description/explanation of the measurement instruments and a treatment method to analyse the data recovered from the instruments aforementioned.

This project is organized as follows:

In Chapter 2, we will talk about color and its importance according to the final user application and how the substrate influences in the perceived color. To do it, we will introduce the color theory, an ink to media interaction model and a complete justification of the need to do individual substrate characterization and the value of the automatic media identification and why customer find it interesting and value it.

In Chapter 3, we will discuss on the different substrates attributes and the feasibility to integrate them in a printer to do online measurements. This lead us to select which sensors we need to perform the automatic identification.

In Chapter 4, we present the two sensors selected to our purposes, a spectrophotometer and a gloss meter. It includes recommendations on how to set-up, use and handle the data to make them robust to measurement noise.

In Chapter 5, we propose a method to analyze the captured data to be able to automatically select the media loaded in the printer.

Finally, in Chapter 6, we present the conclusions of this study and the path forward to its implementation in a commercial product.

2. BASIC PRINCIPLES

In this chapter we will present an overview to the color theory. We will indentify the three agents responsible of the color perception and understand the importance of the substrate. We will talk about its impact to obtain accurate colors, other image quality and printing reliability properties.

At the end of this chapter the reader should understand the need to do an individual substrate characterization and the consequences of not doing it or applying it wrong on the printer.

2.1. INTRODUCTION

Color has tried to be described many times along our history. I would like to point at this thought by Isaac Newton where you can guess that color is related with physics but also with psychology.

"For the rays (of light) to speak properly are not coloured.
In them there is nothing else than a certain Power
And Disposition to stir up a Sensation of this or that Colour"
Sir Isaac Newton (1730)

As you can imagine, quite a challenging task has not unified all the voices. From a philosophical point of view, color is defined as the experience that a person experiments when viewing an image. This definition which is too general and also too abstract, allows us to understand many concepts like memory colors[2], color adaptation[3]… which are soft-related with the stimulus (response process) and are directly related with the brain (perceptual process).

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[2] *Memory color is a chromatic adaptation that our brain does to correct color stimulus. It consists of adapting the color of a known object in an image turning it to its real color. As an example, if we view a photographic paper under a laboratory red light we will continue viewing a "white" sheet of paper.*
[3] *Color adaptation is a mechanism by which our brain changes the color of an image depending on the colors that are surrounding these images. For example, if we view a white sheet of paper over a black table, it will look brighter than the same sheet of paper on a white table.*

As it is difficult to quantify color using this definition, we will work with this other one that states that 'being colored a particular determinate color or shade is equivalent to having a particular spectral reflectance[4], illuminance[5], or emittance[6] that looks that color to a particular perceiver in specific viewing conditions' (Thompson,1995). It is important to note that you need an illuminant, an observer and a surface to modify the spectral distribution of the light source in a specific way to match that color.

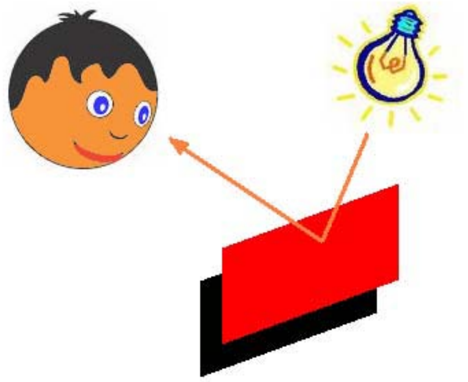

Figure 2-1 Light, substrate, viewer interaction

The importance of this block is make the reader able to understand the necessity of knowing which type of paper you are using, because it will change the color laid on it. This change in the color cast, which seems to be insignificant, takes special relevance when we are talking about advertising. As an example, we can think on the CocaCola Company who has its special red called CocaCola red. When they make an advertising campaign, they want the same red to be printed over the cardboard for a box, banner papers for outdoor advertisements, office paper for internal documents… So it will be necessary to know which paper and which illuminant are you using to apply properly a correction to obtain the same color. This will be widely explained in the next sections.

2.2. ILLUMINANTS

We can define an illuminant as a certain power distribution through the visible spectrum. Extending this definition, we say that a light source is a subgroup that include all the

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[4] *Reflectance is the ratio of the reflected light to the incident light under specified viewing conditions.*
[5] *Illuminance is the luminous flux incident per unit of area (ATSM E 284).*
[6] *Emittance is the luminous flux emitted per unit of area.*

illuminants with the feasibility of been made. So, we can summarize that, all light sources can be specified as an illuminant, but not all illuminants can be physically realized as a light source.

A standard way to characterize an illuminant is comparing its power distribution with the ones that a black body radiator will have at a certain temperature typically measured in Kelvin degrees. In Physics, a black body is an object that absorbs all electromagnetic radiation that falls onto it. No radiation passes through it and none is reflected. It is this lack of both transmission and reflection to which the name refers. These properties make black bodies ideal sources of thermal radiation. That is, the amount and wavelength (color) of electromagnetic radiation they emit is directly related to their temperature. Black bodies below around 700 K (430 °C) produce very little radiation at visible wavelengths and appear black (hence the name). However, black bodies above this temperature, produce radiation at visible wavelengths starting at red, going through orange, yellow, and white before ending up at blue as the temperature increases.

Figure 2-2 Color of a black body radiator (Kº)

Black bodies, are fully described by Plank's law which establish the relationship between spectral radiance of electromagnetic radiation at all wavelengths and the temperature T at which the black body is.

$$I(\lambda, T) = \frac{2hc^2}{\lambda^5}\frac{1}{e^{\frac{hc}{\lambda kT}}-1} \qquad (1)$$

Where h, k are respectively Plank's and Boltzman's constants, c is the light speed in vacuum, I is the spectral radiance or energy per unit time per unit surface area per unit solid angle per unit wavelength.

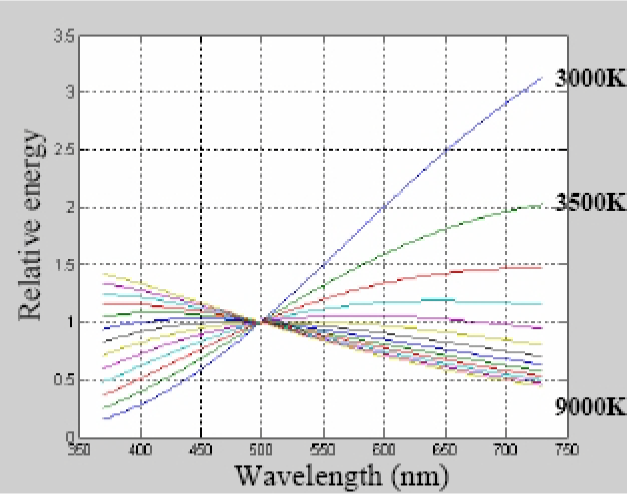

Figure 2-3 Spectrum of a Black Body Radiator (Kº)

Figure 2-3 shows the representation of the Plank's law for different color temperatures. It has been normalized at 500nm. The shape of the curve indicates us the color appearance that the light emitted will have. High values at 750nm are yellow-red colored lights while high values at 400nm are blue lights.

In order to allow images or colors be recorded under different light sources, The International Commission on Illumination (usually abbreviated CIE for its French name), defined the standards illuminants. Each of these illuminants is known with a combination of a letter and a number. The letter points its family type.

A	Incandescent
C	Sunlight
D50	Daylight - Red Shade
D65	Daylight - Neutral
D75	Daylight - Blue Shade
F2	Cool white flourescent
F7	Broad band white flourescent
F11	TL84 flourescent
F12	Ultralume 3000 flourescent

Table 1 Illuminants (www.xrite.com)

The illuminant **A** is used to represent incandescent lighting such as a filament lamp. The **C** series of illuminants are based on filtering illuminant A. They are generally considered to be a poor approximation of any common light source and their use is not recommended. The **D** series of illuminants are constructed to represent natural daylight. They are difficult to produce artificially. The number in the name of a D series illuminant represents the correlated color temperature (CCT) of the source; for example, illuminant D50 has a CCT of 5000 K, and D65 has one of 6500 K. The **F** series of illuminants represent various types of fluorescent lighting. Illuminant F2 represents cool white fluorescent; F11 represents narrow-band fluorescent. F7 and F8 represent *daylight fluorescent*, and are often used as approximations of D65 and D50, respectively.

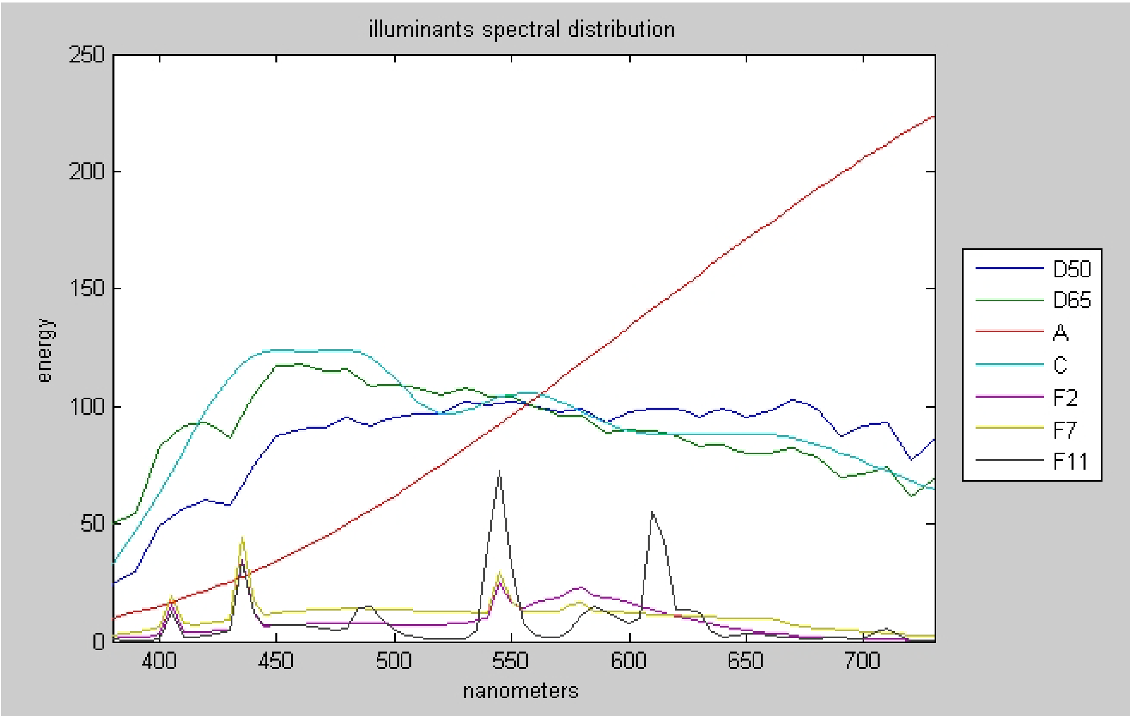

Figure 2-4 Illuminant's spectrum distribution

As you can see comparing Figure 2-3 Spectrum of a Black Body Radiator (Kº) and Figure 2-4 Illuminant's spectrum distribution, the black body radiator it is just a rough approximation of the spectral distribution of a an illuminant. In spite of this fact it is quite useful to describe the form of a spectrum with a simple number and this is the reason for the extended use in computer screens, TFT's (Thin Film Transistor) or photo cameras.

2.3. OBSERVERS

2.3.1. The human visual system

During the next few lines, we are going to understand how our body gets the visual signals. The receptor that we have intended for this use is obviously, our eyes. Figure 2-5 shows the diagram of an eye. We can see that the left side of the illustration have all the parts regarding to focusing, whereas the right side has the optic nerve that drives the signals to the brain and the vein and artery that supply the blood. For our goal, understanding color, the most important part is the retina. The word retina comes from the Latin *rete* meaning net, and refers to the network of photo-receptor cells and their connections. Note that the retina has two uniformities, a blind spot where the optic nerve is connected and the fovea.

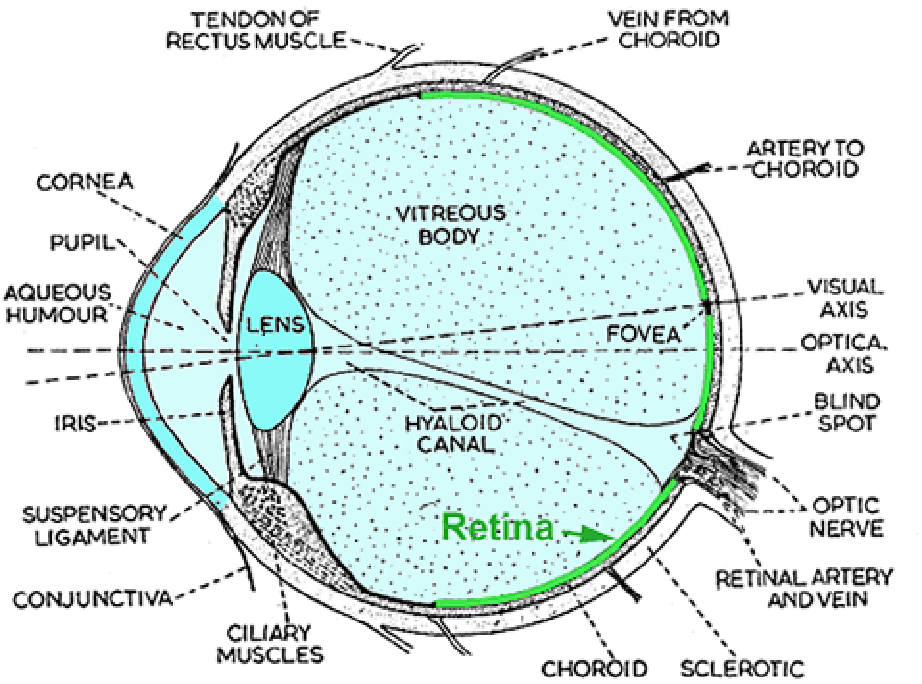

Figure 2-5 Eye diagram

As the retina is the one that has the photo-receptors, it is here where we are going to focus in. In a further description of the retina it has five layers of cells and cell connections. The photo-sensitive cells, *rods* and *cones (named according to their shape*), are at the back. Rods detect very small amount of light such as starlight. Because there is only one type of pigment, we only see objects as shades of gray. As the amount of light increases, rows cease sending signals to the brain. Cones are our color receptors. There are three types of cones called L, M and S each of them responding differently to light of various wavelengths (Long, Medium and Short respectively). All three overlap, so there is no 'dark' band in the rainbow. As with the rods, individual cones cannot distinguish wavelength. Our color sense comes about through the comparison of the responses of the different types of cone. Red looks red because the L-cones (long wave cones) are stimulated more that the other types. Their response to different wavelengths is shown in the next figure.

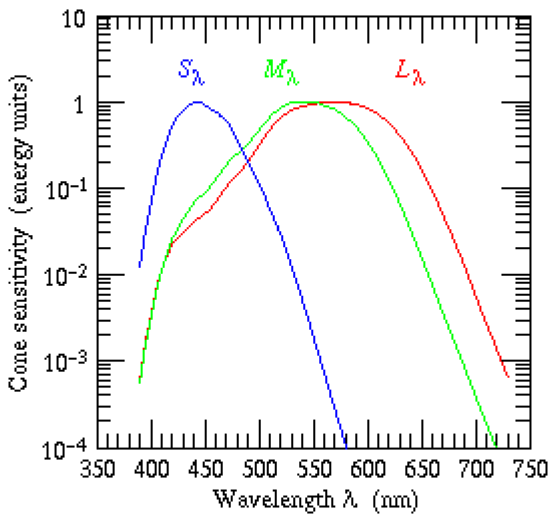

Figure 2-6 Cone sensitivity

The other layers perform complex interconnections to accumulate the signal into *ganglion cells*. The ganglion cells have long *axons* (signal carrying threads) leading across the retina, through the optic nerve bundle, and ending in the *lateral geniculate nuclei* in the brain. Some scientists think of the retina as a *part* of the brain, since it is intimately connected and performs complex analysis within its own structure.

2.3.2. CIE[7] standard observers

Once again, in an effort to standardize the observers, the CIE commission made an experiment trying to calculate the responses of a standard viewer. This experiment is known as the CIE Color Matching Experiment. It consists in a screen where a color is projected. Then the viewer has three different light sources corresponding to the primaries (RGB[8]) in an additive system and a system to change their intensity. Users have to change the amount

[7] *Commission Internationale de l'Eclairage, www.colour.org and www.cie.co.at .*
[8] *RGB is the acronym of Red, Green and Blue.*

of RGB until they match the color of the two screens. Then the value of this RGB intensity combination which is known as Tristimulus values is recorded. A diagram of the set-up can be found in the Figure 2-7 The color matching experiment .

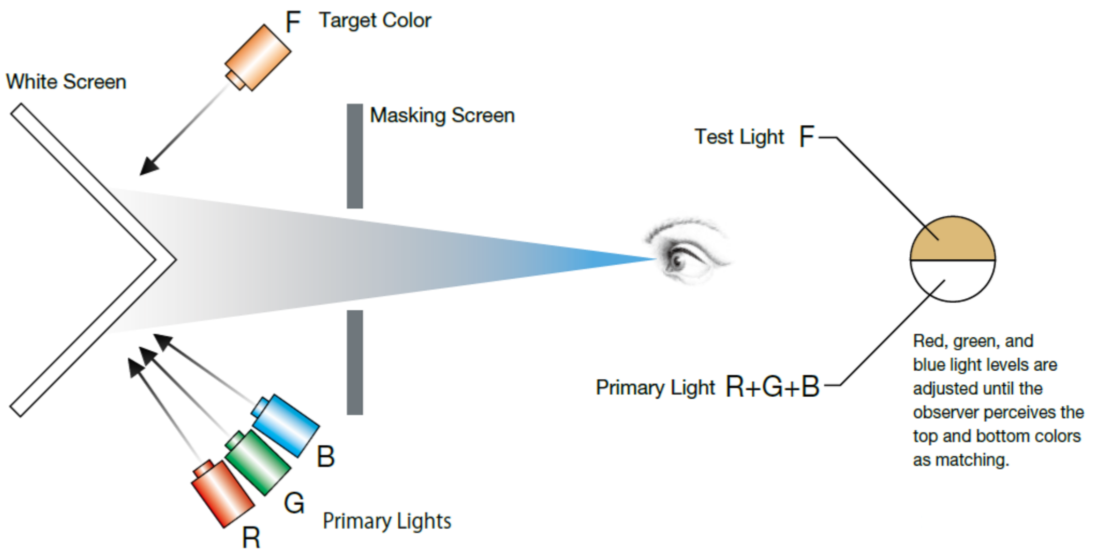

Figure 2-7 The color matching experiment

The result of this experiment was the CIE Standard Observer curves both for the 2 degrees in 1931 and for the 10 degrees 1964. First the experiment was done for the 2 degrees observer because at that time it was thought that the cones were concentrated in the foveal region. Later it was determined that the cones were spread beyond the fovea and the experiment had to be redone in 1964 for the CIE 10º Standard Observer. Even now, these curves are still valid. They are the best approach that we have to characterize the human visual system.

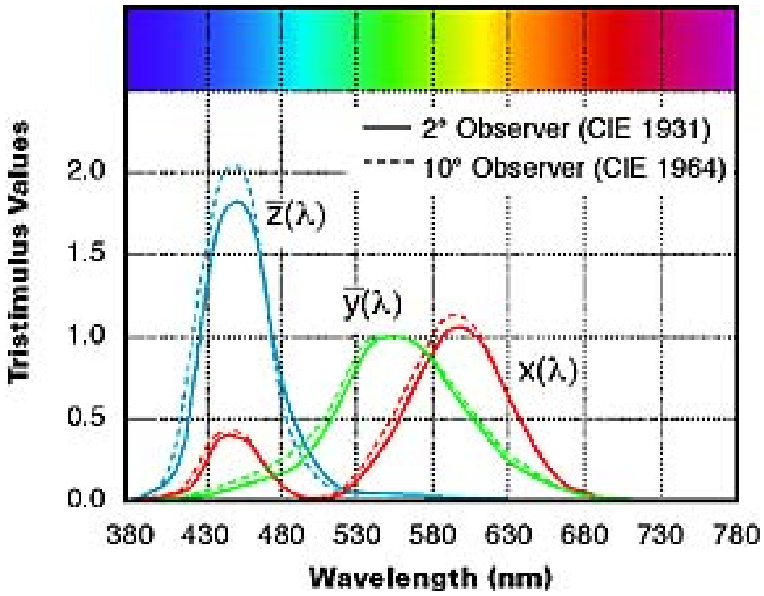

Figure 2-8 CIE standard observer

2.4. SUBSTRATES

2.4.1. Substrate characterization

2.4.1.1. Introduction

Printing is a quite complex action. It requires hardware and firmware interactions (print system), but also ink and media interaction. That means that usually all types of papers that are used in a large format printer need to be characterized first. As a result of that, there are a high number of settings that are paper-dependent grouped under that paper preset name. During the following section we will take a look at some of them, and we will try to understand why it is critical to choose the correct paper preset and why it is so important to have an Automatic Media Identification system.

2.4.1.2. Color related

As we can imagine, paper spectrum (or the paper color) has a great impact on the final color and its accuracy. Although images printed without that correction may still being pleasant to view, the color accuracy is very bad. That means that jobs where color accuracy is critical as print proofs, fine art reproduction or logo colors, would be rejected for the lack of accuracy.

Apart of that, paper can be more or less efficient in ink management. There are papers, typically uncoated papers, where ink drains into their porous surface and the ink is not hold in the surface. That means that they need more ink to have the same color than a coated media.

All paper substrates increase the output color by printing more ink on them. That could lead to the idea that all colors are possible on all medias. In fact what happens is that second order effects appear and it is not possible to print more ink. This amount of ink is known as the ink limit of the paper. One of the most important is cockle effect shown in Figure 2-9. In this photograph we can see the back side of a printed image. It is really easy to appreciate how the paper is distorted forming a kind of bubbles that in some cases may provoke a paper jam in the printer. It is important to see how this effect is strongly related with the amount of ink (area inside the triangle has less cockle).

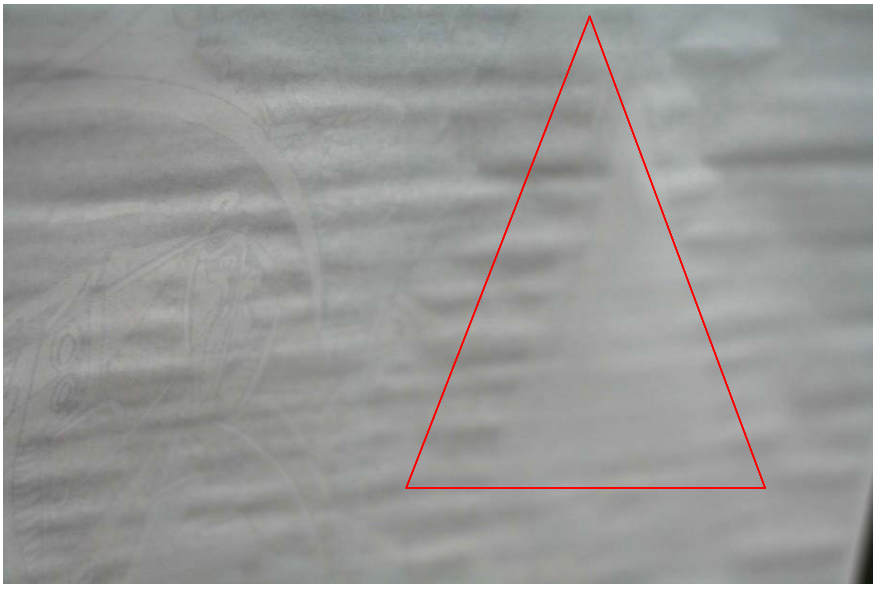

Figure 2-9 Cockle example

This effect is a paper expansion issue. Fibers that get in contact with the ink vehicle (water based vehicle) get expanded while fivers on the opposite side of the paper that continue dry try not to be expanded. As a result the paper is distorted forming a wave pattern. Note that depending on the direction of the fibers, cockle will form the waving in the machine direction (MD) or in the cross direction (CD).

Although it has not a direct impact in color, it is also worth to mention the glossiness of the substrate because of its impact in image appearance.

2.4.1.3. IQ (Image Quality) related

Depending on the paper type and depending on the product, it can be chosen the pen to paper space, or the number of passes that a print head makes over the same piece o paper. That makes printout more robust to grain defects or pen health.

Other examples are the advance factor. Typically thicker papers tend to overadvance while thinner substrates tend to subadvance. So it is needed a factor to compensate for this bias.

Finally depending on the maximum amount of ink and in the paper absorption characteristics, there is a dry time setting that allows the ink to be fixed to the paper. Touching the ink while it stills fresh destroys it, and the plot has to be scraped.

2.4.1.4. Others

There are many other presets. As an example we can talk about the embedded cutter. Taking into account the versatile media set, there are papers from $45g/m^2$ to canvas, there is a setting to select if the cutter is able to cut this material at the end of the print job and the cutter speed.

Another example is if a paper is valid for a calibration. As an example imagine doing a color calibration on a HP Transparent Clear Film. Due to the fact that the media is transparent and the printing platen is black, it is impossible to measure anything on it.

2.4.2. Ink

2.4.2.1. Dye ink

A dye can generally be described as a colored substance that has an affinity to the substrate to which it is being applied. The dye is generally applied in an aqueous solution, in our case the ink vehicle, where it is dissolved to color it and form the ink. Dyes appear to be colored because they absorb some wavelengths of light preferentially.

In Figure 2-10, can be seen how the layer of ink absorbs some color frequencies (dyeing the light), then it reflects on the paper (that also reflects each frequency according to its spectrum) and the ink layer absorbs again the same color frequencies reinforcing the final color.

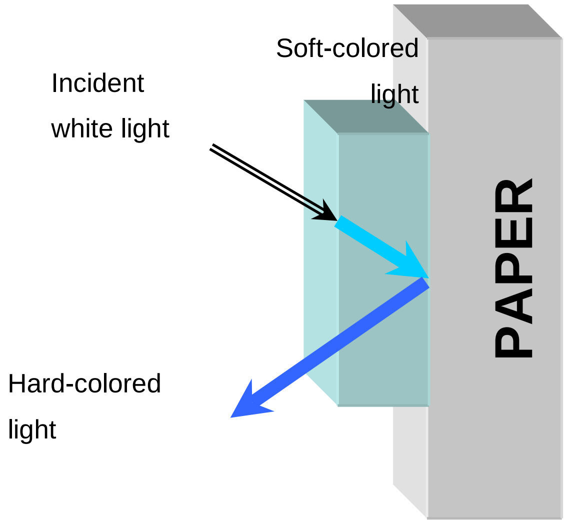

Figure 2-10 Dye ink behaviour

Typically, dye ink is more chromatic (colors are more vivid), it is more linear to produce secondary colors (easy to predict color) and has a better affinity with the paper (prevents smudge fastness), although it may require a mordant[9] to improve the fastness of the dye on the substrate. Another important characteristic is that it is cheaper than pigmented ink and its industrialization process is easier and also cheaper.

As a cons, dye ink are more sensitive to light and generally colors tend to fade (light fastness) faster than pigmented ink. Other cons are the permanence and the color stability. That's why it is mainly used in the CAD market where these properties are not highly required.

Some dyes can be precipitated with an inert salt to produce a lake pigment, and based on the salt used they could be aluminium lake, calcium lake or barium lake pigments. In this solution we have an ink vehicle (typically with an aqueous base) mixed with some dyes to color it.

[9] *A mordant is a substance used to set dyes on fabrics, tissue or paper fibers sections by forming a coordination complex with the dye which then attaches to the fabric, tissue or paper fibers.*

2.4.2.2. Pigmented ink

Most pigments used in manufacturing are dry colorants, usually ground into a fine powder with particle sizes in the order of magnitude of the micrometres. This powder is added to a vehicle or binder (ink vehicle), a relatively neutral or colorless material that suspends the pigment and gives the ink its adhesion.

A distinction is usually made between a pigment, which is insoluble in the vehicle (resulting in a suspension) and has no affinity for the substrate, and a dye, which either is itself a liquid or is soluble in its vehicle (resulting in a solution) and has more affinity for the substrate. One important difference is that light gets scattered when impacts in these particles as it is illustrated in the next figure.

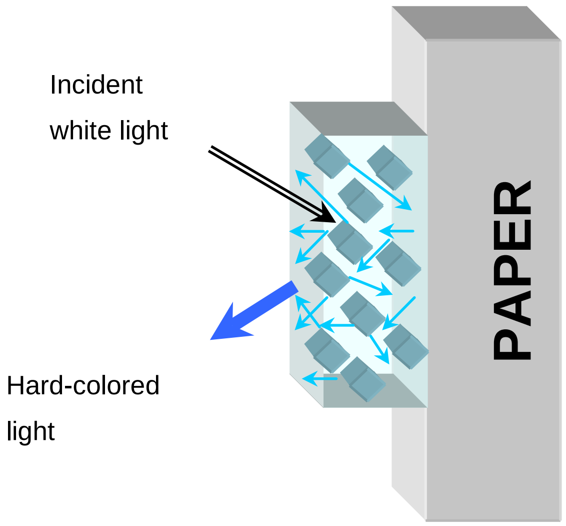

Figure 2-11 Pigmented ink behaviour

Pigmented inks are technologically more advanced. They are more resistant to light and more stable. That is why they are used in the photographic and fine art market where printouts have to be durable without losing their color properties.

Most modern pigmented inks use particles in the order of magnitude of the nanometre and are called nanopigments.

2.4.3. Ink to media interaction

2.4.3.1. Beer-Lambert theory

The "Beer-Lambert" theory considers a system that absorbs light but does not scatter light. That is why it is used to model dye ink to media interaction. The absorption of light is a "first order" process. This means the rate at which irradiance decreases ($-dI/dx$) depends on the magnitude of irradiance, $I(x)$, at location x. Equation (2) describes the process. The proportionality constant, K, is a characteristic of the material that is absorbing the light. If we solve this first order differential equation, we obtain a more familiar expression of the Beer-Lambert law, shown if various forms in equations (3).

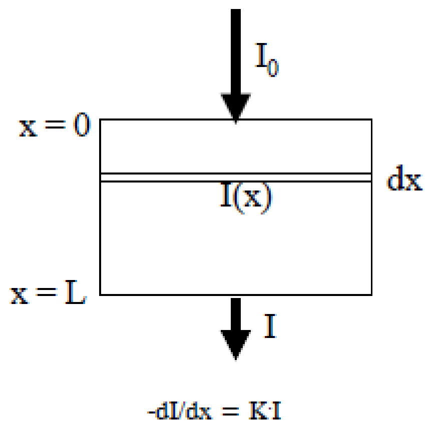

Figure 2-12 Beer-Lamberty model

$$\frac{-dI}{dx} = KI \qquad (2)$$

$$\frac{-dI}{I} = Kdx \quad \text{or} \quad -ln\left(\frac{I}{I_o}\right) = Kx \quad \text{or} \quad \frac{I}{I_o} = e^{-KL} \qquad (3)$$

If x is in mm, the constant, K, is in units of mm^{-1} and is called an absorption coefficient. It can be described as a probability constant. The larger the value of K, the greater the probability a photon will be absorbed.

This model was widely used for dye inks where light does not scatter.

2.4.3.2. *Kubelka-Munk theory*

The Kubelka-Munk theory is a theory of radiation transfer that attempts to relate the spectral reflectance properties of a material to its constitution. The theory is most widely used colorant recipe prediction. In such applications the Kubelka-Munk theory is used to characterize a set of colorants (dyes or pigments) in terms of their absorption and scattering coefficients. The theory allows the prediction of spectral reflectance for any known mixture of the colorants. The inverse problem – that of determining the mixture required for a known spectral reflectance – is central to all computer recipe prediction systems.

First consider only the flux of light in the down direction. Without scattering, the change in irradiance would be $dI = -KIdx$ according to the Beer-Lambert law. But scattering also decreases the flux of light in the down direction. Kubelka and Munk suggested the scattering phenomenon, like the absorption phenomenon, is a first order phenomenon. Thus, we expand the first order differential equation to include two other terms, as follows.

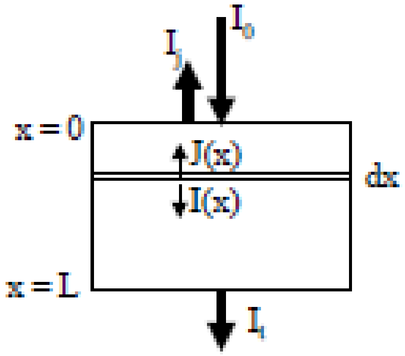

Figure 2-13 Kubelka-Munk model

$$dI = -KIdx - SIdx + SJdx \qquad (4)$$

S is the Kubelka-Munk scattering coefficient and has the same units (inverse length) as the Kubelka-Munk absorption coefficient. I is the flux in the DOWN direction and is a positive value when the flux is going down. According to Kubelka-Munk sign conventions, J is the flux of light in the UP direction. The value of J is positive when light is going up. The term $+SJdx$ simply tell us that UP moving flux is scattered to add to the DOWN moving flux. So, to describe the rate of change in UP moving flux, we have a second differential equation.

$$dJ = -KJdx - SJdx + SIdx \qquad (5)$$

Notice that we ignore light flux in the horizontal direction. In a bulk material of infinite lateral extent, the lateral dimensions are assumed to be much larger than the mean free paths, $1/K$ and $1/S$, for absorption and scattering in the material. This means no light leaks out the edges of the material due to lateral scattering. We will see later, however, how lateral scattering has a significant impact on image tone reproduction by halftone processes.

Equations (4) and (5) are two differential equations with two flux terms, I and J. If we consider the value of $I = It$ at the bottom of the material, then we can define a transmittance.

$$T = \frac{I_t}{I_o} \qquad (6)$$

Similarly, we can define a reflectance factor, R, in terms of the up flux at the surface of the paper.

$$R = \frac{J_r}{I_o} \qquad (7)$$

Clearly, it would be desirable to solve differential equations (4) and (5) to obtain analytical expressions for R and T. While the differential equations are simple in differential form, finding useful analytical solutions made Kubelka and Munk famous.

Wyszecki and Styles {"Color Science", 2nd Edition, 1982, bibliography ref[4]} give solutions in terms of R and T. The solutions are rather complicated transcendental functions. However, when you look at the functions for R and T, remember they are functions in terms on only four parameters of the system. These are S = scattering coefficient; K = absorption coefficient, L = thickness of the layer; and Rg = reflectance of the material (if any) behind the layer.

$$R = f_1(S, K, L, R_g) \text{ and } S = f_2(S, K, L, R_g) \qquad (8)$$

The particular form of the functions, f_1 and f_2, depend on the boundary conditions of the system. The general solutions can be expressed as follows.

$$a = \frac{(S+K)}{S} \qquad (9)$$

$$b = \sqrt{a^2 - 1} \qquad (10)$$

$$R = \frac{1 - R_g[a - b\coth(bSL)]}{a - R_g + b\coth(bSL)} \qquad (11)$$

$$T = \frac{b}{a\sinh(bSL) + b\coth(bSL)} \qquad (12)$$

2.5. COLOR THEORY

2.5.1. Introduction

In the previous sections, we have studied the illuminants and its differences with light sources, we have also studied the observer characterization with the CIE standard observer model and finally we have studied the substrate. In our case the substrate is a mixture of the paper spectrum and the ink spectrum whose relation is described with the Kubelka-Munk K-M theory. As it was introduced, these are the three factors that determine the color.

After all these previous work, we are able to measure color as follows. The process is illustrated in Figure 2-14 Color computation.

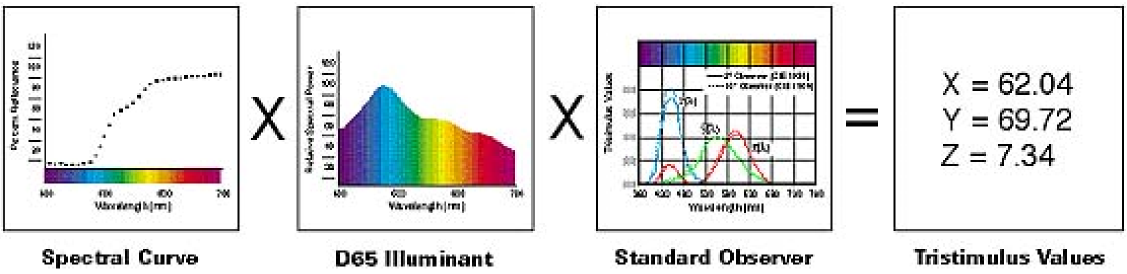

Figure 2-14 Color computation

CIE *XYZ* tristimulus values can be calculated by the integration of the reflectance values *R(l)*, the relative spectral energy distributions of the illuminant *E(l)*, and the standard observer functions *x(l)*, *y(l)*, and *z(l)*. The integration is approximated by summation, thus:

$$X = \frac{1}{k} \sum R(I)E(I)x(I), \quad (13)$$

$$Y = \frac{1}{k} \sum R(I)E(I)y(I), \quad (14)$$

$$Z = \frac{1}{k} \sum R(I)E(I)z(I), \quad (15)$$

where $k = \sum E(I)y(I)$ *(16) and* l *= wavelength.*

Any specific method for associating tristimulus values with each color is called a color space. In the next section we are going to talk about the CIE Lab color space and its benefits.

2.5.2. CIE L*a*b* color space

CIELAB allows the specification of color stimuli in terms of a three-dimensional space. The *L**-axis is known as the lightness and extends from 0 (black) to 100 (white). The other two coordinates *a** and *b** represent redness-greenness and yellowness-blueness respectively and its range is -128 to 128 (8bits).

Samples for which a* = b* = 0 are achromatic and thus the *L**-axis represents the achromatic scale of greys from black to white. The quantities $L*$, $a*$, and $b*$ are obtained from the tristimulus values according to the following transformations:

$$L^* = 116 \cdot f\left(\frac{Y}{Y_n}\right) - 16, \qquad (17)$$

$$a^* = 500\left[f\left(\frac{X}{X_n}\right) - f\left(\frac{Y}{Y_n}\right)\right], \quad (18)$$

$$b^* = 200\left[f\left(\frac{Y}{Y_n}\right) - f\left(\frac{Z}{Z_n}\right)\right], \quad (19)$$

$$\text{Where } f(t) = \begin{cases} t^{\frac{1}{3}}, \ t > \left(\frac{6}{29}\right)^3 \\ \frac{1}{3}\left(\frac{29}{6}\right)^2 t + \frac{4}{29}, \ otherwise \end{cases} \qquad (20)$$

where *Xn*, *Yn*, and *Zn* are the *X*, *Y* and *Z values* for the illuminant that was used for the calculation of *X*, *Y*, and *Z* of the sample.

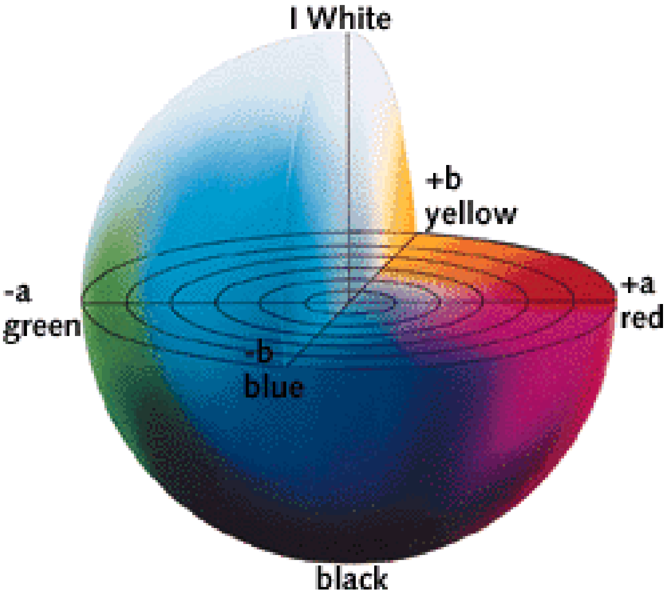

Figure 2-15 CIE Lab color space representation

2.5.3. CIE L*C*h color space

Depending on the application it is useful to work in cylindrical coordinates. In that case we will talk about the CIE L*C*h color space (Lightness, Chroma[10] and Hue[11]). Lightness which is the same than in CIE L*a*b* is the height (z) of the cylinder. Chroma which is the amount of color respect to the gray axis is the modulus of the vector (r). Finally Hue which is the tonality is the angle (φ).

To make the conversion between CIE L*a*b* and CIE L*C*h here is the following transformation:

$$C^*_{ab} = \sqrt{a^{*2} + b^{*2}} \qquad (21)$$

$$h_{ab} = tan^{-1}\left(\frac{b^*}{a^*}\right) \qquad (22)$$

[10] *Chroma is the attribute of color used to indicate the degree of departure of the color from a gray of the same lightness.*
[11] *Hue is the attribute of a color according to its similarity to red, yellow, green and blue or to a combination of adjacent pairs of these colors considered in a closed color ring.*

The opposite conversion is can be obtained easily reversing the previous equations.

2.5.4. Color differences and errors

2.5.4.1. Introduction

One of the multiple advantages of the CIE $L^*a^*b^*$ color space is that colors pretend to be linearly distributed in terms of color perception. That is really useful to make a color difference metric. In this section we are going to present the more common three of them.

Color differences are measured in error increments known as delta E, ΔE or DE. The definition of 1ΔE is 1 JND (Just Noticeable Difference). That pretends that an error smaller that 1ΔE is not visible for a naked human eye.

2.5.4.2. CIE DE76

This is the simplest ΔE formula. Its definition is just the Euclidean distance between two colors in the CIE $L^*a^*b^*$ color space. It is really useful as it is really simple to compute and to remember.

$$CIE\ \Delta E_{74}^{*} = \sqrt{(L_1^* - L_2^*)^2 + (a_1^* - a_2^*)^2 + (b_1^* - b_2^*)^2} \qquad (23)$$

2.5.4.3. CIE DE94

The 1976 definition was extended to address perceptual non-uniformities, while retaining the L*a*b* color space, by the introduction of application-specific weights derived from an automotive paint test's tolerance data.

$$CIE\ \Delta E_{94}^{*} = \sqrt{\left(\frac{L_2^* - L_1^*}{K_L}\right)^2 + \left(\frac{C_2^* - C_1^*}{1 + K_1 C_1^*}\right)^2 + \left(\frac{h_2^* - h_1^*}{1 + K_2 C_1^*}\right)^2} \qquad (24)$$

where the weighting factor K depends on the application and is specified in the Table 2 ΔE94 constants.

	graphic arts	textiles
K_L	1	2
K_1	0.045	0.048
K_2	0.015	0.014

Table 2 ΔE94 constants

2.5.4.4. CIE DE2000

Finally after a study on color differences it was found that there were areas on the CIE L*a*b* color space where a difference smaller than 1 ΔE76 was detected while there were other areas where a difference greater than 1 ΔE76 was not detected. In other words, the color space was not perceptually uniform.

To solve this problem the CIE refined their definition, adding five corrections:

- A hue rotation term (RT), to deal with the problematic blue region (hue angles in the neighbourhood of 275°):
- Compensation for neutral colors (the primed values in the L*C*h differences)
- Compensation for lightness (SL)
- Compensation for chroma (SC)
- Compensation for hue (SH)

The final equation is very difficult to remember and needs to be programmed to use it easily. We introduce it here as a reference.

$$CIE\ \Delta E_{00}^{*} = \sqrt{\left(\frac{\Delta L'}{S_L}\right)^2 + \left(\frac{\Delta C'}{S_C}\right)^2 + \left(\frac{\Delta H'}{S_H}\right)^2 + R_T \frac{\Delta C'}{S_C}\frac{\Delta H'}{S_H}} \qquad (25)$$

$$\Delta L' = L_2^* - L_1^* \qquad (26)$$

$$\bar{L} = \frac{L_2^* + L_1^*}{2} \qquad (27)$$

$$\bar{C} = \frac{C_2^* + C_1^*}{2} \qquad (28)$$

$$a_1' = a_1 + \frac{a_1}{2}\left(1 - \sqrt{\frac{\overline{C}^7}{\overline{C}^7 + 25^7}}\right) \quad (29)$$

$$a_2' = a_2 + \frac{a_2}{2}\left(1 - \sqrt{\frac{\overline{C}^7}{\overline{C}^7 + 25^7}}\right) \quad (30)$$

$$\overline{C'} = \frac{C_1' + C_2'}{2} \quad (31)$$

$$\Delta C^1 = C_1' - C_2' \quad (32)$$

where

$$C_1' = \sqrt{a_1'^2 + b_1^2} \quad (33)$$

$$C_2' = \sqrt{a_2'^2 + b_2^2} \quad (34)$$

$$h_1' = tan^{-1}\left(\frac{b_1}{a_1'}\right) \ mod \ 2\pi \quad (35)$$

$$h_2' = tan^{-1}\left(\frac{b_2}{a_2'}\right) \ mod \ 2\pi \quad (36)$$

$$\Delta h' = \begin{cases} h_2' - h_1' & , |h_1' - h_2'| \le \pi \\ h_2' - h_1' + 2\pi & , |h_1' - h_2'| > \pi; h_2' \le h_1' \\ h_2' - h_1' - 2\pi & , |h_1' - h_2'| > \pi; h_2' > h_1' \end{cases} \quad (37)$$

$$\Delta \overline{H}' = 2\sqrt{C_1' C_2'} \, sin\left(\frac{\Delta h'}{2}\right) \quad (38)$$

$$\overline{H}' = \begin{cases} \frac{h_1' + h_2' + 2\pi}{2} & , |h_1' - h_2'| > \pi \\ \frac{h_1' + h_2'}{2} & , |h_1' - h_2'| \le \pi \end{cases} \quad (39)$$

$$T = 1 - 0.17\,cos\left(\overline{H}' - \frac{\pi}{6}\right) + 0.24\,cos\left(2\overline{H}'\right) + 0.32\,cos\left(3\overline{H}' - \frac{\pi}{30}\right) - 0.2\,cos\left(4\overline{H}' - \frac{21\pi}{60}\right) \quad (40)$$

$$S_L = 1 + \frac{1+0.015\left(\bar{L}-50\right)^2}{\sqrt{20+\left(\bar{L}-50\right)^2}} \quad (41)$$

$$S_C = 1 + 0.045\overline{C}' \quad (42)$$

$$S_H = 1 + 0.015\overline{C}'T \quad (43)$$

$$R_T = -2\sqrt{\frac{\overline{C}'^7}{\overline{C}'^7+25^7}}\sin\left[\frac{\pi}{6}exp\left(-\left[\frac{\overline{H}'-275^\circ}{25}\right]^2\right)\right] \quad (44)$$

2.6. SUMMARY

In this chapter we have exposed all the variable influencing in color and the complexity of printing in a determinate substrate. At this point we would like to consider the consequences of making a wrong decision when loading a new media roll.

We can make a distinction between fatal errors and marginal errors, and we present a couple of examples to illustrate them.

We *call fatal errors* to the ones that make the printer stop printing. Sometimes, they even need to reboot the printer and in some corner cases it is possible to damage it. This type of errors, although serious, are easy to detect and easy to solve. Just recall that they happen because of not choosing the media on the printer to match the media that has been loaded. So, once the customer detects that there has been an issue, he looks for the solution and learn that choosing the media type is not trivial. As an example imagine that this customer wants to print a photograph on a canvas substrate. He loads the canvas roll on the printer and selects that it is photographic media, because he wants to print a photo. This is a common error. The selection on the front panel is for media type and not for the print job type. As a consequence, the printer may try to cut the photograph once it has finished, but the embedded cutter is not able to cut canvas. So cutter is going to suffer a paper jam, the customer will have to remove it, and the printer will need to be rebooted.

We define *marginal errors* to the ones that make the printer work in a mode under its capabilities. These errors are much more difficult to detect. There will be many customers that will think that this is the best performance that the printer can provide.

Similar to the first example, now imagine that the customer buy an expensive roll of fine art material to print a photograph. Again, thinking on the content he selects photographic media. In this case the cutter also works with fine arts media, so there will be neither any jam nor any reboot that makes the customer think anything is wrong. In this case users will be faced to two possible issues:

Photographic paper is bluish and printer prints yellowish to compensate it. So, because of fine art paper is yellowish and printer print yellowish, the print out will be too much yellowish. This is wrong color accuracy.

Photographic paper prints with *photo* black ink, specially designed to work with this paper while fine art paper works with *matte* black ink. This is a curious ink to media interaction where the darkest black on photo paper is obtained with photo black ink while in the other case is obtained with matte black ink. As a consequence, the print out would be lighter because it is using photo black ink on fine art paper.

What will happen is that the customer will get a copy of his photograph that could have been much better with a correct choice. Most users will think that the photograph is just enough and more of them will think that this is a printer limitation, that printer cannot do better, and will be disappointed. Finally only a minority of them will look for the issue and its solution.

There are many other examples that could be mention. Printer has more than twentieth different paper presets to deal with this characterization. Studies on the Asiatic market show that the vast majority of the installed printer based use always HP High Gloss photo paper, which was the default paper (they never change it) to print in many different substrates.

Due to all the exposed issues, HP has been working in a low cost solution to make an automatic system to determine the loaded paper type without any user intervention. Benefits are clear, make customer life easy, ensure maximum printout quality and avoid disappointed customer that thinks that image quality is limited by the printer.

During the next chapter we will go through the paper characteristics, how do we measure them and what can we do with our embedded sensors to automatically identify them. There will be also a description of the HP media product line, both with the interest for the customers and with the change in the characteristics that identify them.

3. PAPER FAMILIES

This chapter will talk about different paper physical properties, how to measure them and which measurement instruments can be embedded in a printer to do this online and non-destructive analysis.

Finally we will also talk about how these properties are used to do the HP media portfolio to cover as much applications as possible and how this is reflected in the measured properties.

3.1. PAPER CHARACTERISTICS

During this block, we are going to define the most important paper characteristics. It is necessary to know them to understand the different paper usages that exist. As it was introduced, there are many paper families designed for an intended use. Each of this families, boost one, or more than one, of this characteristics normally penalizing others as a trade-off. The description will be organized in four sections attending to the nature of the characteristic. After that we are going to select the most relevant of them for our purposes and finally there will be a summary collecting all the conclusions.

3.1.1. Physical Properties

Basis Weight or Grammage

The basis weight, substance or grammage is obviously the most fundamental property of paper board. The basis weight of paper is the weight per area unit. This can be expressed as the weight in grams per square meter (GSM or g/M^2), pounds per 1000 sq. ft. or weight in Kg or pounds per ream (500 sheets) of a specific size. The standard procedure of measuring basis weight is laid out in TAPPI T 410, SCAN P6, DIN53104 & ISO: BSENISO536

Bulk

Bulk is another very important parameter of paper particularly for printers. Bulk is a term used to indicate volume or thickness in relation to weight. It is the reciprocal of density (weight per unit volume). It is calculated from caliper and basis weight. Bulk (cubic centimeter/g) = Thickness (cm) / Basis Weight (g/cm^2). Sheet bulk relates to many other sheet properties. A decrease in bulk or in other words an increase in density makes the sheet smoother, glossier, less opaque, darker, lower in strength etc.

High bulk is desirable in absorbent papers while lower bulk is preferred for printing papers such as Indian paper dictionary paper etc.

Book Bulk: Book bulk is defined as the overall thickness in mm of a given number of paper sheets. The bulking number is defined as number of sheets required to bulk 25 mm or approximately 1". The standard procedure of measuring book bulk is laid out in TAPPI T 500, SCAN P7 DIN53105, ISO 534, BS: EN ISO20534

Caliper or Thickness

For a given basis weight, thickness determines how bulky or dense paper is. A well beaten/refined pulp[12], short fiber pulp such as hard wood or straw pulp, highly filled or loaded paper will show lower thickness for a given basis weight. Thickness or caliper of paper is measured with a micrometer as the perpendicular distance between two circular, plane, parallel surfaces under a pressure of 1 kg./ CM^2. Uniform caliper is for good roll building and subsequent printing. Variations in caliper, can affect several basic properties including strength, optical and roll quality. The standard procedure for thickness measurement is explained in TAPPI T 411.

Figure 3-1 Paper thickness example

[12] A slurry of cellulose fibers and water which is the basic ingredient for paper.

Curl

Paper curl can be defined as a systematic deviation of a sheet from a flat form. It results from the release of stresses that are introduced into the sheet during manufacture and subsequent use. Paper curl has been a persistent quality issue and is increasingly important for paper grades being subjected to high speed printing, xerography and high precision converting processes.

There are three basic types of curl, **mechanical** curl, **structural** curl and **moisture** curl. Mechanical curl develops when one side of the paper is stretched beyond its elastic limits. One example of this is the curl in the sheet which forms near the centre of a roll. Structural curl is caused by two-sidedness in the sheet, which is a difference in the level of fines[13], fillers[14], fiber area density or fiber orientation through the sheet thickness. Moisture curl can develop when the paper sheet is being offset printed. One side of the sheet may pick up more moisture than the other, the higher moisture side releases the built in drying strains and the paper will curl towards the drier. The standard procedure for curl measurement is explained in TAPPI T 466 & T520.

Figure 3-2 Curl example

Dimensional Stability

Dimensional changes in paper originate in the swelling and contraction of the individual fibers. Cellulose fibers (main constituent of paper) swell in diameter from 15 to 20% from dry condition to saturation point. Since most of the fiber in paper sheet are aligned in the machine run direction, absorption and de-absorption of moisture by paper causes the

[13] Everything solid in the furnish that is small enough to pass through a screen.
[14] Materials like clay (a natural substance used as both filler and coating ingredient to improve a paper's smoothness, brightness, opacity and affinity for ink) added to pulp before it is formed into paper to improve the sheet's smoothness, brightness and printability.

change in cross direction[15] (aka CD) dimension. Such changes in dimension may seriously affect register in printing processes. Furthermore, dimensional changes cause undesirable cockling[16] and curling. It is not possible to be accurate about the degree of this swelling because paper-making fibers differ considerably in this property, and because the irregular cross-section of fibers creates difficulty in defining diameter. All papers expand with increased moisture content and contract with decreased moisture content, but the rate and extent of changes vary with different papers. Dimensional stability of paper can be improved by avoiding fiber to absorb moisture. Well sized papers have better dimensional stability.

Formation

Formation is an indicator of how uniformly the fibers and fillers are distributed in the sheet. Formation plays an important role as most of the paper properties depend on it. These will affect properties like caliper, opacity, strength etc. Paper formation also affects the coating capabilities and printing characteristics of the paper. There is no standard method or unit to express formation. It is a relative or subjective evaluation.

Friction

Friction is the resisting force that occurs between two paper or paperboard surfaces in contact when the surfaces are brought to slide against each other. This property is measured as a coefficient of friction, which is the ratio of the frictional force, to a force acting perpendicular to the two surfaces.

Two components of friction can be measured, these being static and kinetic friction. Static friction is the force resisting initial motion between the surfaces and kinetic friction is the force resisting motion of the two surfaces sliding against each other when already sliding at a constant speed. This property is also important in printing papers, since a specific coefficient of friction is needed so that individual sheets will slide over each other, otherwise double press feeding may result.

There are two methods of measuring the co-efficient of friction of paper. The first one, which uses Incline Plane, is explained in TAPPI T 548 & T815, the second method, which uses Horizontal Plane is explained in TAPPI T 549 & T816.

[15] Cross Direction it is perpendicular to the paper path or Machine Direction.
[16] A wavy, rippled, puckered finish.

Machine and Cross Direction

In paper machine approach flow system, when stock passes through pressure screen, the fibers are oriented lengthwise. Fiber alignment can be altered to some extent if stock velocity is less than wire speed. So, all papers have a definite grain direction due to greater orientation of fibers in the direction of paper machine run. This grain direction is known as machine direction (aka MD). The cross direction (aka CD) is the direction of paper at right angles to the machine direction. Some of the properties vary with the MD and CD and hence the values are reported in both the directions. The sheets which have all relevant properties same or almost same in both directions are known as 'square sheet'.

While sheeting the paper, machine and cross direction have to be taken into account and the sheet cutting to be done to suit the end must use these requirements. As an example, book papers fold better and the book stays open better if the sheets are out so that the machine direction runs up and down the pages.

Moisture

Almost all grade of paper has some percentage of moisture[17] depending on relative humidity, type of pulp used, degree of refining and chemical used. Water has the effect of plasticizing the cellulose fiber and of relaxing and weakening the inter-fiber bonding. The absorption and reflectance of certain bands of infrared and microwave radiation by paper are affected by its moisture content. Moisture control is also significant to the economic aspect of paper making. Water comes free. Poor moisture control can adversely affect many paper properties.

The absolute moisture content is expressed as a percentage of the paper/paperboard weight. The sample is generally not conditioned while doing this test. The standard procedure is laid out in TAPPI T 412 and ISO 287, SCAN P4.

Smoothness

Smoothness is concerned with the surface contour of paper. It is the flatness of the surface under testing conditions which considers roughness, levelness, and compressibility. In most of the uses of paper, the characteristic of the surface is of great importance. It is common to say that paper has a "smooth" or a "rough" texture. The terms "finish" and "pattern" are

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[17] A liquid such as water in the form of very small drops, either in the air, in a substance, or on a surface.

frequently used in describing the contour or appearance of paper surfaces. Smoothness of the paper will often determine whether or not it can be successfully printed.

There are three different test methods described in TAPPI T 479, TAPPI T 538 and TAPPI T 555.

Figure 3-3 Paper smoothness examples

In Figure 3-3, from left to right, we can see HP matte litho realistic paper, HP Textured fine art paper and HP Canvas Satin paper. In this example lack of smoothness is not a defect but a feature. Textured media is used in art reproduction prints where this texture is well perceived.

Wire side and Felt side

Felt side is also referred as top side. It refers to the side which is in contact with the paper machine wire during manufacturing is called the wire side. The other side is top side. Before a thin layer of fibers deposit on machine wire, fines and fillers drain out hence wire side has less fines and fillers compared to top side. Certain properties such as smoothness, texture and ink absorbency differ between wire and felt side and it is customary to measure these properties on both sides. This difference of properties on two sides of paper is known as two-sidedness. Highly filled or loaded or paper made from short fiber pulp will show higher two-sidedness.

In case of paper to be printed on one side only, best results are obtained by printing on felt side.

The standard procedure is described in TAPPI T 455.

3.1.2. Optical Properties

Brightness

Brightness may or may not add much value to the 'useful' properties of the paper but it is the most important selling feature.

Brightness is defined as the percentage reflectance of blue light only at a wavelength of 457 nm. Brightness is arbitrarily defined, but carefully standardized, blue reflectance that is used throughout the pulp and paper industry for the control of mill processes and in certain types of research and development programs. **Brightness is not whiteness!** However, the brightness values of the pulps and pigments going into the paper provide an excellent measure of the maximum whiteness that can be achieved with proper tinting.

Brightness is measured with two different standards - TAPPI/GE and ISO. Though there is correlation, ISO brightness of a sample is usually lower by 1-1.5 units over GE brightness. The standards are as per TAPPI T 452.

Whiteness

Whiteness refers to the extent that paper diffusely reflects light of all wave lengths throughout the visible spectrum. Whiteness is an appearance term. Its measure is understood as the percent of light reflectance for the whole wavelength range.

The procedural standards for the measurement of whiteness are explained in ISO 11475.

Color

Color is an aesthetic value. Color may appear different when viewed under a different light source. The color of paper, like of other materials, depends in a complicated way on the characteristics of the observer and a number of physical factors such as the spectral energy distribution of the illuminant, the geometry of illuminating and viewing, the nature and extent of the surround and the optical characteristics of the paper itself.

The quality of light given off by a sheet as described by its hue (tint), saturation (strength), and value (darkness or lightness), but a commonly used system to measure it is the CIE L,a,b system. This is based on the idea of color opposites.

L	luminance and varies from 100 for perfect white to 0 for perfect black.
a	redness to greenness.
b	yellowness to blueness.

Table 3 Coordinates in the CIE Lab color system.

A whiter sheet reflects equal amounts of red, green, and blue light - the entire visual spectrum. While most balanced white sheets have a slightly yellowish cast, most people will perceive a sheet with a slightly blue tint to be whiter and that is the reason why industry include an agent called shadowing dyes to turn the paper a little bit more bluish.

Figure 3-4 Papers with different color

Fluorescence

Fluorescence measures the amount of fluorescent whitening agent (FWA) present in the paper. Optical brightening agent absorbs UV light and re-emits it as visible blue light. Under lighting with a UV component this makes the paper appear more blue and brighter. All high white grades have high levels of optical brightener. FWA are commonly used to get a brighter appearance that customers use to evaluate it as quality value.

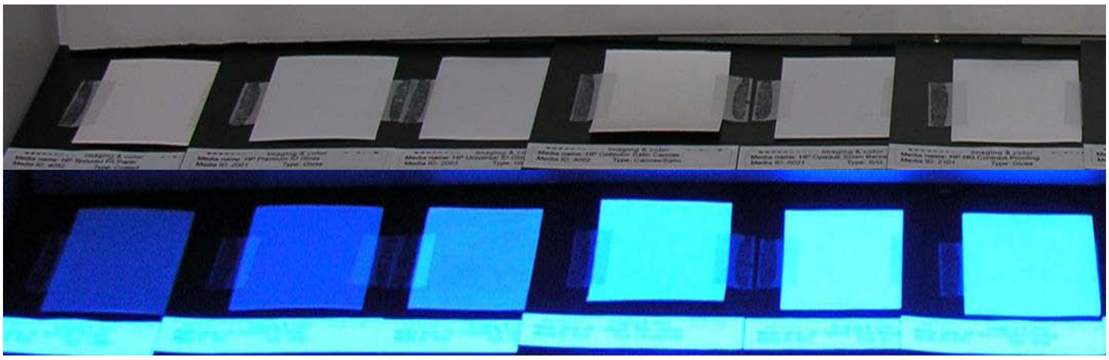

Figure 3-5 Papers with Fluorescent Whitening Agents (FWA)

In the upper band in Figure 3-5 there are six different paper types. The three on the left side are fine art paper made mainly with cotton to obtain a lighter media while the three on the right are office paper of different qualities that use FWA (which is more cheaper than cotton) to obtain the same effect. We can see that under a fluorescent illuminant they all have the same level of lightness, but when we illuminate them with UV light, then fine art material is not reflecting the light in the visible spectrum while fluorescent whitening agents from office paper reflects all this energy in the visible spectrum in a bluish band at about 440-460nm range.

Gloss

It refers to the specular and diffuse measurement of reflected light component against a known standard. The level of gloss desired is very dependent on the end use of the paper. Gloss and smoothness are different properties and are not dependent on each other.

Gloss is the specular reflection of light, which is reflected at an equal and opposite angle that what it is formed by the illuminant and the surface. It is normally measured at 75° or 20°. Printed and varnished surfaces are measured at 60° angle. The standard procedures are laid out in TAPPI T 480.

Opacity

Opacity is measured as the percentage of light absorbed by a sheet of paper. A perfectly opaque paper is the one that is absolutely impervious to the passage of all visible light. It is the ratio of diffused reflectance and the reflectance of single sheet backed by a black background. The opacity of paper is influenced by thickness, amount and kind of filler, degree of bleaching and coating etc.

Opacity is important in book printing where both sides of paper are printed. The procedural standards are explained in ISO 2471 and TAPPI T425.

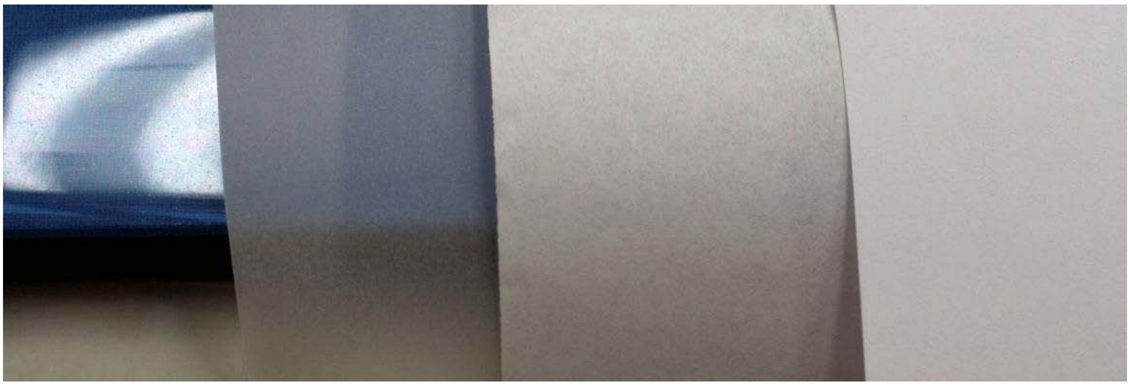

Figure 3-6 Opacity example

In the photograph in Figure 3-6 we can see four papers ordered by opacity from less opaque (HP transparent clear film) at the left side to more opaque (HP Bright White Inkjet paper) at the right side.

3.1.3. Strength Properties

Bursting Strength

Bursting strength establishes how much pressure paper can tolerate before rupture. It is important for bag paper.

The standards procedure to measure it is described in TAPPI T 403.

Compressibility

It is defined as the reduction in thickness under compressive forces or pressure. It influences the ability of paper to change its surface contour and to conform to and make contact with the printing plate or blanket during printing impression. Compressibility is measured as a ratio of roughness under two different standard pressures in a Parker Print Surf tester.

Folding Endurance (Double Folds)

Folding endurance is the paper's capability of withstanding multiple folds before it breaks. It is defined as the number of double folds that a strip of 15 mm wide and 100 mm length can withstand under a specified load before it breaks. Folding endurance has been useful in measuring the deterioration of paper upon aging. Long and flexible fibers provide high folding endurance.

The procedural standards for measuring Folding Endurance using MIT tester are explained in TAPPI T 511.

Hardness

It is the degree to which paper will resist indentation by some other material such as a stylus, pen or printing plate.

Ply Bond/ Scott Bond

The Internal Bond Strength of paper or paperboard (also known as Ply Bond Strength or Z Directional Strength) is the ability of the product to resist splitting when a tensile load is applied through the paper's thickness i.e. in the Z direction of the sheet. It is a measure of the internal strength of the sheet.

The standard measurement procedures are explained in TAPPI T 403 & T833 & SCAN P80.

Resiliency

It is defined as the ability of paper to recover its original thickness and surface contour after release of the compressive forces of printing nips.

Stiffness

Stiffness is the measure of force required to bend a paper through a specified angle. A sheet that is too stiff will cause problems in copier machines where it must traverse over, under, and around feed rollers.

Stiffness (Taber): A measure of flexural rigidity, Stiffness is the bending moment (g-cm or mNm) required to deflect the free and of a 1.5 in wide vertically clamped sample 15° from its center line when load is applied 50 mm away from the clamp; measured in MD and CD. The procedural standards are explained in TAPPI T 489 and ISO 2491.

Stretch (Elongation)

Stretch is the amount of distortion which paper undergoes under tensile stress. Stretch is higher in cross direction than machine direction.

The tensile strain developed in a test sample at maximum tensile strength before rupture, measure as the percentage increase in the length of the sample to the original length. The procedural standards are explained in TAPPI T 494

Tearing Resistance

Tearing resistance indicates the behavior of paper in various end use situations; such as packaging papers where the ability to absorb shocks is essential. Fiber length and inter-fiber bonding are both important factors in tearing strength. The fact that longer fibers improve tear strength is well recognized. The explanation is that longer fibers tend to distribute the stress over a greater area, over more fibers and more bonds, while short fibers allow the stress to be concentrated in a smaller area.

Tensile Strength

The tensile force required to produce a rupture in a strip of paperboard, measured in MD and CD, expressed in kN/m. Tensile strength is indicative of fiber strength, fiber bonding and fiber length. Tensile strength can be used as a potential indicator of resistance to web breaking during printing or converting. The procedural standards are explained in TAPPI T 494.

Wet Strength

Some grades of paper such as tea bag paper or coffee filter paper come in contact with water in use. So these papers have to be strong enough to withstand tear, rupture or falling apart when saturated with water. To impart wet strength, paper are treated chemically.

3.1.4. Miscellaneous Properties

Ash Content

The residue left after complete combustion of paper at high temperature. It is generally expressed as percent of original test sample and represents filler content in the paper. As it is ash content is not important property of paper but in some grade of papers such as filter papers are ash free and other such as cigarette tissue have certain level of filler to control cigarette burning rate.

The ash content measurement procedural standards are explained in TAPPI T 413, SCAN P5, ISO 1762.

Dirt Content

The paper may have number of dirt specks or contraries. These specks can be any unwanted foreign particle that is visible to the eye such as bark, undigested wood (shives), pitch, rust, plastic, slime etc. For pulp, paper and board the number or area covered by such specks on both surfaces and sometimes in the body of the material, can be estimated in either reflected or transmitted light.

The number of specks of each area are expressed either as mm^2/Kg for pulp or mm^2/m^2 for paper

Permanence

Permanence is the degree to which paper resists deterioration over time. Permanent paper can resist large chemical and physical changes over and extended time (several hundred years). These papers are generally acid-free with alkaline reserve and a reasonably high initial strength. Papers containing pure cellulose fiber are more permanent. Permanency is desirable in currency, bond and record papers.

Pin Holes

It refers to the imperfections in paper which appear as minute holes upon looking through the sheet. They originate from foreign particles, which are pressed through the sheet. Absence of pin hole in electrical grade papers is very important.

Porosity

Because paper is composed of a randomly felted layer of fiber, it follows that the structure has a varying degree of porosity. Thus, the ability of fluids, to penetrate the structure of paper becomes a property that is both highly significant to the use of paper. Paper is a highly porous material and contains as much as 70% air. Porosity is a highly critical factor in Printing Papers, Laminating Paper, Filter Paper, Cigarette Paper, Bag Paper, Anti-tarnish Paper and Label Paper. Porosity of sheet is an indication of absorptivity or the ability of the sheets to accept ink or water.

Air Resistance (Gurely Method): It is the resistance to the passage of air, offered by the paper structure, when a pressure difference exists between two sides of paper. It is measured as the time for a given volume of air to flow through a specimen under specified conditions. Air resistance is indirect indicator of degree of beating, compaction of fibers and type and amount of fillers.

The Gurely Method is explained in TAPPI T 460 and TAPPI T 536 for low and high air resistance respectively. Air Resistance (Sheffield Method): is explained in TAPPI T 547

Print Quality

It is the degree to which the appearance and other properties of a print approach a desired result. Lot of parameters in paper surface like roughness, gloss, ink absorption, whiteness, brightness… affect this.

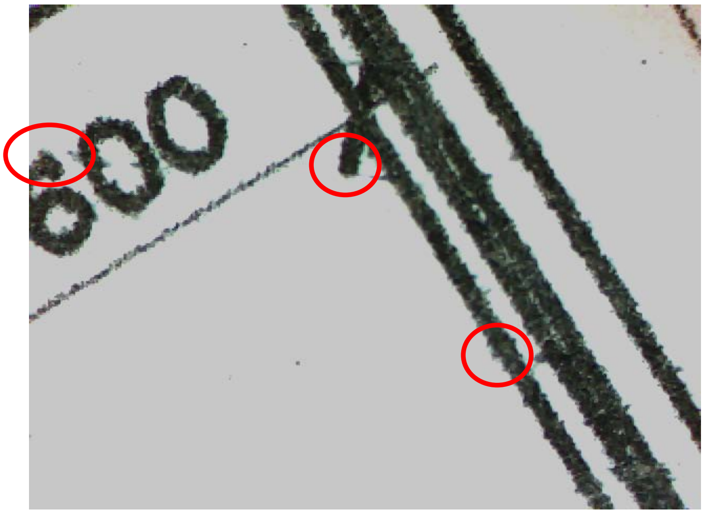

Figure 3-7 Example of print quality

In Figure 3-7 we have a clear example of a quality issue due to the print quality that this paper can deliver. In this photograph users may see that text and lines are not crisp at the edges. While this may be understood as a printer related issue, the reality is that if the user change to an appropriate media, this issue will disappear. What is happening here is that once an ejected drop reaches the substrate it is spilled following the fibers of the paper instead of being absorbed.

Printability

The extent to which properties of paper lends them to the true reproduction of the original artwork. This is influenced by the printing process and can be evaluated in terms of - dot reproduction, dot gain, print gloss, hue shift and print uniformity.

Sizing / Cobb

Because paper is composed of a randomly felted layer of fiber, its structure has a varying degree of porosity. Thus, the ability of fluids, both liquid and gaseous, to penetrate the structure of paper becomes a property that is both highly significant to the use of paper. The need to limit the spreading of ink resulted in "sizing" the paper with gelatinous vegetable materials which had the effect of sealing or filling the surface pores. Later, the term "sizing" was applied to the treatment of paper stock prior to the formation of the sheet, with water-repellent materials such as rosin or wax.

The surface water absorption over 60 seconds, expressed in g/m2 is measured by Cobb Test. The procedural Standards are explained in TAPPI T 441.

Water Absorption (EDGE WICK)

Water absorption at the edge, expressed in kg/m2, using Wick Test. Board surface is sealed with waterproof tape on both sides, weighed, placed in water at 80°F for 20 minutes and weighed again to measure the water absorbed by wicking. It is an important test for measuring the water absorption capacity of cup stock grade, which is used for the manufacture of soft drink cups.

3.1.5. Properties analysis

After all the definitions, we are going to analyze them. All these properties are important in paper industry, but only some of them are related with our objectives. Furthermore, some others are not easily measurable and even some of them are not measurable at all. The most adequate way to order these characteristics that we have found is in the following tablese. Again they are grouped as we previously did.

If we take a look to the first table, we can see that there are two properties marked as measurable that have a binary result (yes / no). We are talking about the direction of the fibers (MD or CD) and about the side of the paper (Felt or wire side). In the comment field we noted it as detectable. Furthermore, media for printing always have the fibers aligned in machine direction. This is the reason by which these two properties do not provide any information and are not useful. Another attribute that it is not useful is the formation due to the lack of a defined method to measure it. We also have to discard all these characteristics that are not able to be measured on line, such as grammage, curl, bulk and moisture. It is not possible to measure curl on line, because during the manufacturing process paper is put under stress. The rest of them are still good candidates to be analyzed in this study.

Physical Properties

	Measurable	On-line measure	Comments	Destructive analysis	Measurement instrument
Basis Weight or Grammage	yes	no		no	weight
Bulk	yes	no	thickness/Basis weight	no	weight micrometer
Caliper or Thickness	yes	yes		no	micrometer
Curl	yes	no	only the CD curl named cockle	no	micrometer
Dimensional Stability	yes	yes	measure climatic conditions may vary	no	micrometer
Formation (*)	no	---	(classifiable)	no	microscope
Friction	yes	yes		no	dynamometer
Machine and Cross Direction	yes	yes	always MD for printing medias (detectable)	no	microscope
Moisture	yes	no	measure climatic conditions may vary	no	weight
Smoothness	yes	yes	(classifiable)	no	microscope
Wire side and Felt side	yes	yes	always Felt side for printing medias (detectable)	no	microscope

(*) It is a subjective property. You can classify by it but not measure it.

Table 4 Media physical properties

The next table (Table 5) is without any doubt the most useful. All of its attributes are on-line measurable and its tests are not destructive essays. In addition the measurement instruments employed to get these measures are not only affordable but also we actually have them. Due to the system restrictions, measures can not be done following the TAPPI standards. This implies that it is not possible to get the absolute value of the measures which is not our goal. It will be enough if different papers provide different measures with the necessary resolution to differentiate them even with the variability (measure noise) added by the measurement instrument.

Optical Properties

Look at the table in the next page Table 5 Media optical properties.

	Measurable	On-line measure	Comments	Destructive analysis	Measurement instrument
Brightness	yes	yes		no	spectrophotometer
Whiteness	yes	yes		no	spectrophotometer
Color (*)	yes	yes		no	spectrophotometer
Fluorescence (**)	yes	yes	give an estimation	no	spectrophotometer
Gloss	yes	yes		no	gloss meter
Opacity	yes	yes	give an estimation	no	gloss meter

(**) A spectrophotometer can estimate its value. Measure will be correlated but quantity will not be specified.

(*) Under a specified illuminant

Table 5 Media optical properties

Strength properties are by definition destructive techniques. This method always consists in subject a batch of the material to a stress situation until it breaks o deforms. So finally the batch has been altered and it is not valid to use it again. This is the reason to discard the analysis of all the properties contained in Table 6. It is important to remark that in case a destructive analysis could be performed, these attributes would give us a precious information o determinate what type of paper it would be.

Strength Properties

	Measurable	On-line measure	Comments	Destructive analysis	Measurement instrument
Bursting Strength	yes	no	breakage	yes	manometer
Compressibility	yes	yes	deformation	yes	micrometer
Folding Endurance	yes	no	long time analysis	yes	---
Hardness	no	yes	deformation (classifiable)	yes	---
Ply Bond/ Scott Bond	yes	no	breakage	yes	dynamometer
Resiliency	yes	yes	deformation	yes	micrometer
Stiffness	yes	no		no	dynamometer
Stretch (Elongation)	yes	no	breakage	yes	dynamometer
Tearing Resistance	yes	no	breakage	yes	dynamometer
Tensile Strength	yes	no	breakage	yes	dynamometer
Wet Strength	yes	no	breakage	yes	dynamometer

Table 6 Media strength properties

Miscellaneous properties are the ones that do not fit in any of the previous categories. Most of them are related with the print quality concept. As an example it is desirable that a good quality printed photograph has to last all his life without loosing its color. Obviously this is an ideal case and nowadays we have to agree a 200 of years without fading. Returning to the analysis and following the same criteria, we have to discard permanence, sizing and water absorption. Moreover, permanence measurement is an estimation obtained in an accelerated test method and through an extrapolation of the values. So different criteria or different methods would provide different time values. Printability and print quality itself are not measurable. They are just evaluated and compared between each copy according to the human judgment. The TAPPI[18] standard process to determine ash and dirt content determines that it is necessary to burn a batch of paper, so it forces a destructive analysis. However, these inorganic fillers have their own absorption pattern under infrared light. This test can be done on line, but the measurement instrument required is too expensive. The rest of characteristics, pin holes and porosity are still good candidates to known about the paper type.

Miscellaneous Properties

	Measurable	On-line measure	Comments	Destructive analysis	Measurement instrument
Ash Content	yes	yes	they survive the burning of cellulose at 575°C	yes	incinerator(*)
Dirt Content	yes	yes	they survive the burning of cellulose at 575°C	yes	incinerator(*)
Permanence	no	no	long time (estimated)	yes	---
Pin Holes	yes	yes		no	microscope
Porosity	yes	yes	pressure difference	no	chronometer
Print Quality	no	no	(evaluated)	no	---
Printability	no	no		no	---
Sizing / Cobb	yes	no	deformation	yes	weight
Water Absorption	yes	no	deformation	yes	weight

(*) almost all inorganic fillers exhibit characteristic absorption patterns in the near-infrared region.

Table 7 Media miscellaneous properties

[18] The leading association for the worldwide pulp, paper, packaging and converting industries.

3.1.6. Allowed properties

At this point, it is important to recover the intention of this project and the specifications and resources to solve it. It was stated as a priority to perform a non-destructive analysis. By the other way, we also are limited by the measurement instruments available to us. Fortunately we can use a spectrophotometer and a glossmeter. These two instruments are able to provide all the optical properties listed before. And last but not least, it has to be an on-line device that gets the measurements. It is a hard constraint because near all the properties need a set up process that forces them to be performed in a laboratory.

It is interesting to think about the limitations imposed. On the one hand, a destructive analysis could be easily negotiated if destroying an small patch provides concluding results. On the other hand, increasing the number of measurement instruments it is not allowed due to cost increase reasons. All these technical measurement instruments are too expensive. Furthermore, integrating all these instruments to get on-line measurements would be a risky project. It is important to note that designing a device to classify paper means that all the measurement instruments have to be included in each device triggering its cost.

So following these guides and after this analysis we can conclude that the most important allowed properties to look at are:

Analyzed properties
Brightness
Whiteness
Color
Fluorescence
Gloss
Opacity

Table 8 Analyzed media properties

After the color knowledge acquired along the Chapter 2 we are ready to understand that brightness, whiteness, color and fluorescence properties are dependent on the spectrum appearance that the paper has and that this measured spectrum depends on the illuminant that we use. So we can take the conclusion that brightness is correlated with the amount of energy that is reflected by the paper, whiteness and color are related with its distribution along the visible range and fluorescence is related with the distribution in the edge between the visible spectrum and the non visible ultra violet light. As an example, in the Figure 3-8 we can see the typical spectral power distribution illuminated under a D50 illuminant, starting at 380nm till 739nm in steps of 10 nm.

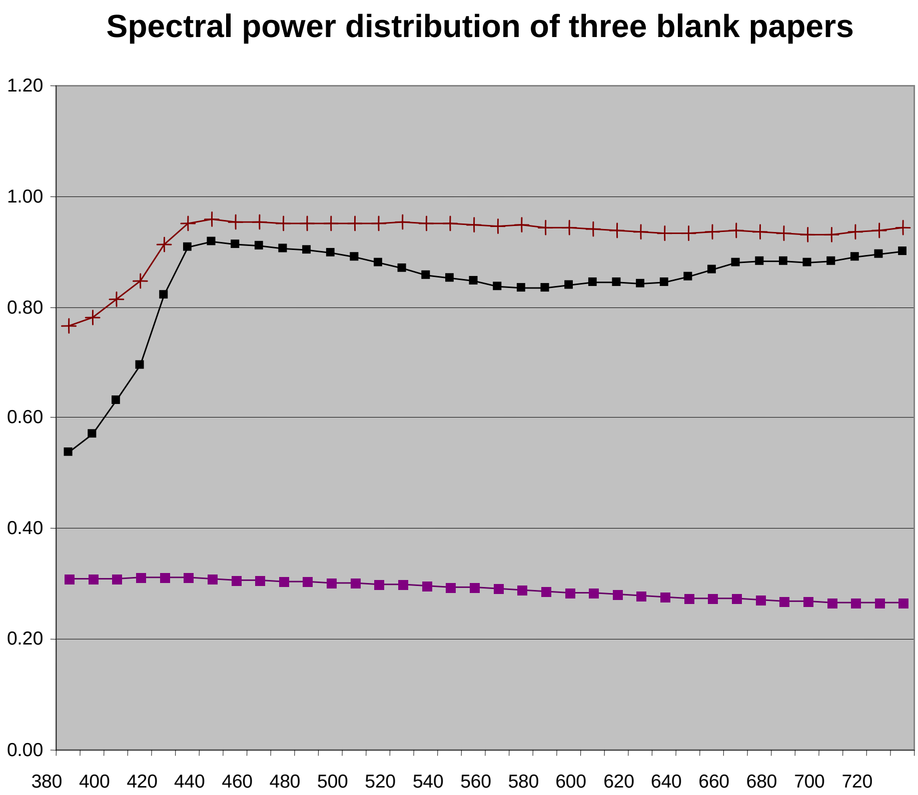

Figure 3-8 Blanck paper spectral power distribution

Paper represented in brown is the lightest and the whitest one as it is the one that reflects more energy and its specter is near equally distributed. The black paper has a bluish cast due to the lack of energy near 580nm wavelength. Both of them have FWA (Fluorescence whitening agents) in different degree shown in the lack of energy in the ultraviolet range near the 380nm. The last one, it is a white batch that reflects a low amount of energy. This means that the purple line represents a grayish paper. It is important to remark that a perfect diffuser would have a plain spectrum through all the wavelengths and a reflective index of a hundred per cent.

3.2. PAPER FAMILIES & HP PORTFOLIO

Due to the big amount of different applications, HP has developed a collection of media solutions to address all customer needs. In the Table 9 HP Media list there is the HP portfolio grouped by family. Inside each group there can be several papers to cover sub-applications and/or market segmentation.

Paper family	Commercial name
Bond and Coated Paper	HP Bright White Inkjet Paper HP Coated Paper HP Universal Heavyweight Coated Paper HP Heavyweight Coated Paper Super Heavyweight Coated Paper
Photo Paper	HP Universal Instant-dry Photo Gloss HP Universal Instant-dry Photo Semi-Gloss HP Premium Instant-dry Photo Gloss HP Premium Instant-dry Photo Satin
Proofing Paper	HP Professional High-gloss Contract Proofing Paper HP Professional Semi-gloss Contract Proofing Paper HP Proofing Matte
Fine Art Material	HP Hahnemühle Textured Fine Art Paper HP Hahnemühle Smooth Fine Art Paper HP Matte Litho-realistic Paper
Films	Transparent/Clear Film Matte Film HP Backlit Film
Technical Paper	Natural Tracing Paper Translucent Bond Vellum
Canvas	HP Collector Satin Canvas HP Professional Matte Canvas
Banner	HP Opaque Scrim Banner

Table 9 HP Media list

Along the following sections we are going to describe the design intention of each paper family. Although we are going to comment on the most typical applications, they are not limited to them.

Bond and Coated Paper

This family covers all office applications. The HP Bright White Inkjet paper establishes the entry price to this category. It is intended to print mainly CAD[19] plots (lines) and text. It is what most users understand as paper. The next level in quality is HP Coated paper. This paper has a coating layer on top of the paper that holds the ink pigment in the surface to obtain vivid colors and preserves the dot shape. This media has been developed to print in color GIS[20] images and also high quality CAD and text.

Finally we have HP Heavy Weight and super Heavy weight Coated paper. Those papers have the same coating layer that HP Coated. The difference is that each of them is thicker than the previous. That means that the paper is able to hold more ink without cockle deformation and that means a bigger color gamut. They are intended to print indoor posters and presentations. Thickness also helps making them more durable against handleability.

Photo Paper

This family as its name stands is to print photographs. Hp commercializes two different qualities the Universal and the premium. There are two big differences between them, the thickness and the color gamut.

For each of these segments, there are also two possible finishing semi-gloss and high gloss to satisfy customer preferences. This finishing layer only affects to the gloss level as all the other parts are identical. In fact if we measure them with a spectrophotometer we will not be able to see any difference.

Proofing Paper

These papers are designed for proofing applications. They try to emulate the paper that is used in offset presses. Although it can be confused with photographic paper, there are a few characteristic that makes them application dependent.

A very low content of optical brighteners guarantees high color stability and metamerism effects are minimised. They need a big gamut volume to be able to reproduce all the colors that the press can print. In the other hand, print proofs are not durable. This happens because they are intended to predict the color output of the press and once the color

[19] Computed Aided Design the most extended is architectonical plots done with Autodesk AutoCAD.
[20] Geographic Information System.

matching has been checked, the print proof is no longer needed. That's why if you print a photograph on this media, color will fade in a short period of time (typically a few days).

Fine Art Material

These are the papers designed for art reproduction. These materials are chosen by high end photographers to print their art work. They are also widely used in art galleries to print high quality replicas of photographs, pictures and drawings. Without any doubt this is the top of the line printing material.

Films

All these papers are formed by a plastic film with a coating material in one of their surfaces that allows printing ink on them. There are three possible finishing treatments, transparent, matte and backlit. All of them are supposed to be used with retro illumination.

The HP Transparent Clear Film is used to print content that has to be projected with a traditional projector, normally CAD plots or slides. HP Backlit material is widely used in advertisement industry where they print their ads. Later they are displayed in a light box, a typical example is the advertisement at the bus stop.

Technical Paper

This paper family is designed for CAD plots. They are usually very fine and with some grade of transparency. They are used to superimpose different plot revisions and look at the differences. They are also used as draft papers for CAD designs.

It is worth to saying that HP Natural Tracing paper is designed for a special application known as blueprint[21]. This process which is forbidden in Europe is very extended in China and South America.

Canvas

This family could be included in fine art reproduction, at the end they are used in the same way. But there is a big difference that makes adequate to classify them as a different category. The base of this substrate instead of cellulose is a fine mesh of ropes. As ropes

[21] An analog process to make duplicates of technical plots at a very low cost. It uses a plots printed in a translucent paper as a master and a diazo paper (paper emulsionated with a reactive substance) for the duplication. It puts both papers together and exposes them to a UV light that trespass the original as a mask and reacts with the diazo paper. Then the copy is exposed to ammonia to be developed. The copy is in "blue&white" which gives the name to the whole process.

printability is very poor, all of them needs of a coating surface to hold the ink and deliver print quality. They are really easy to identify as they are as a typical canvas but valid for digital printing.

In this family it is possible to find the HP Collector Satin Canvas with a satin finishing that emulates the varnish of a painting, and two matte canvases. The difference between them is in the quality of the mesh that turns the copy more durable and more resistant to the stretching forces that the canvas support when framing.

Banner

As it name stands for, this substrate is intended to print indoor and outdoor banners. It has plastic and textile fibers in its composition to turn it tear resistant. That makes this paper ideal to support external forces as the wind. It has an outstanding resistance to stretch forces. It is also used to print build wraps.

3.3. FAMILY CHARACTERISTICS

In this section we are going to explain how these substrates have been modified to customize them to each particular application and how these physical differences helps us in determining which paper it is.

Bond

Bond paper is a fiber based paper that has to be very competitive in price. This is the reason because it has not a coating layer. In order to make it appear whiter it has a lot of Fluorescent Whitening Agents (FWA) and Shadowing Dyes (SD). It has to absorb the ink really fast as normally fasters printing speed are allowed on this paper. It is somehow thin, in the range of the 90 g/m^2. So it does not accept great inks volumes because of cockle, having a limited gamut.

Technical Paper

This type of paper is always really thin. It is normal to have grammages in the 45 g/m^2 range. As they are so thin, they are normally translucent. That means that if we try to measure with the spectrophotometer on it, we are measuring the print platen, lightness values really low. It has no sense to talk about color on these types of papers because it depends on the surface where the color is measured. As they are translucent, they do not need to appear bright and that is why they use neither FWA nor shadowing dyes.

Coated Paper

Very similar o bond substrates, it has a coating layer. It makes more efficient the ink to media interaction, holding it on the surface, having more gamut for the same amount of ink than bond paper. Inks amounts keeps on limited by cockle effect so the grammage is increased accordingly to heavy weight coated and super heavy weight coated to be more robust to cockle, be able to print more ink and expanding the color gamut in each of them.

Proofing Paper

It has to be a non durable paper. After a proof has been used it can be scrapped. It has to be cheap but with a big gamut to be able to emulate all the colors that the press can reproduce. Color is critical in this application so FWA and SD have been minimized as much as possible meanwhile it has been very important to maintain the maximum lightness possible.

Photo Paper

Photographic paper has to be very durable. Customers want to keep their images as the first day with any trace of light fastness. It is a high quality paper that needs only a small amount of FWA to be bright. By the way it needs of a lot of SD that gives it this characteristic bluish appearance. It is very thick as traditional photographic paper. This thickness makes possible to print as much ink as you want without any trace of cockle. In this case the maximum amount of ink is determined by the dry time necessary to get a handable printout. There are to finishing layers, gloss and semi-gloss, that does not alter its spectrum curve.

Canvas

This is a very particular case. Canvas is an extremely heavy-duty plain-woven fabric and has nothing to be with a wood fiber based paper. HP canvas has a coating layer to turn it printable. It is very flexible and tear resistant to allow the framing of the printout. In this paper ink amount is limited by image quality defects as bleed or coalescence. It has a low level of FWA and any SD. Due to its texture, following the hatch; it is not possible to do any calibration on it.

Fine Art Material

These are high quality material. Instead of wood fiber it uses cotton which is whiter. It does not need of a coating layer and they are really thick. They do not need neither FWA nor SD. They spectrum response is the closest to the ideal spectrum. They are the brightest substrates. They allow big amounts of ink, having a great color gamut with any paper distortion. In other words, they are the high-end of the media family.

Films

Very similar to the technical papers, in fact more of them are for technical applications, they are not fiber based papers. They use a plastic film as the substrate with a coating layer to turn the valid for ink jet printing purposes. As there are no fibers to absorb the ink vehicle they normally have a low ink limit, making color gamut very limited. This is not a big cons as in this applications color is not important.

The exception is the backlit material that supports outstanding amount of ink. As it is designed to work with retro illumination, we have seen in previous chapters that light only trespass one time the ink layer, we need almost double the ink that in a regular light reflected paper.

Banner

This substrate needs to be tear resistant. It is not fiber based. It has a textile hatch plus a plastic layer with a coating layer to turn the valid for ink jet printing purposes.

3.4. SUMMARY

Along this chapter we have had a deep dive in the media ecosystem. We have studied media characteristics and if they are or are not measurable on an automatically and on-line basis. We have introduced the HP media family and what was the customer needs behind it. Finally we have studied which are the paper physical characteristics that the HP media family has to provide the customer a paper suitable for a specific application. In Table 10, you can find a summary with the characteristics that our embedded sensors are able to detect. These will be the base of this work.

Family Properties

	FWA	Shadow. dyes	Lightness	Gloss ratio
Fine Art paper (2)	none	low	high	low
Canvas paper	mid	low	high	low
Photographic paper (3)	low	high	high	high
Proofing paper (3)	mid	low	high	high
Coated paper	high	high	high	low
Technical papers (1)	none	low	low	low
Plain paper	high	high	high	low

(1) 6 HP papers identified in this family
(2) 3 HP papers identified in this family
(3) Distinguish between gloss and semi gloss

Table 10 Paper family properties summary

It is important to note that embedded sensors do not have any type of contact with the substrate itself. They are only able to inspection its surface. Typically most of them have a coating layer so in fact these classification is based on this coating layer differences. That is why we will not be able to make any distinction between HP Coated, HP Heavy Weight Coated and HP Super Heavy Weight Coated papers, since they share the same coating compound.

4. MEASUREMENT INSTRUMENTS

In this chapter we are going to describe the measurement instruments that we are going to use along this project. Each measurement instrument will be described in three subsections: Theoretical description, Commercial version and Measurement challenges.

The devices selected are a spectrophotometer manufactured by X-Rite® and a gloss meter developed in Hewlett-Packard. Both sensors are embedded in the Designjet Z printer family commercialized since 2006 addressed for professional photographers and high-end signage print service providers.

4.1. SPECTROPHOTOMETER

4.1.1. Theoretical description

Spectrophotometers are devices that measure the reflectance factor[22] from materials as a function of wavelength. In case of spectrophotometers which main intention is to measure color, the wavelength region corresponds to the visible spectrum, approximately from 380nm to 780nm.

Typical parts of a spectrophotometer are a source of optical radiation, and optical system to define a standard geometry, a reference, a dispersing element (typically a prism or a diffraction grating), a filter element, a photo detector and a signal processing system.

[22] The reflectance factor is the ratio between the flux measured in a sample and the flux measured of the perfect reflecting diffuser under the same geometric and spectral conditions.

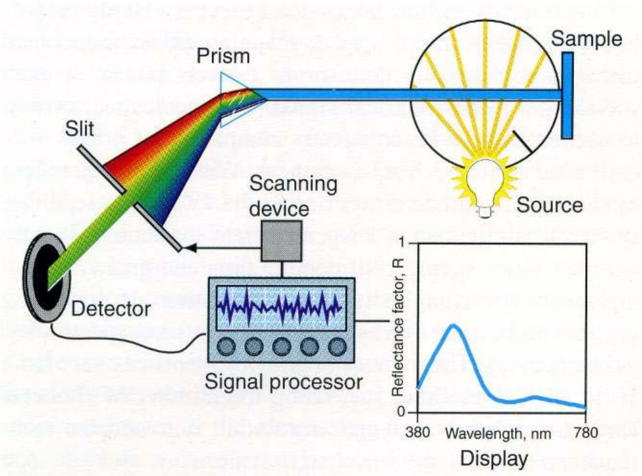

Figure 4-1 Spectrophotometer parts

As technology has been evolving there have been several changes in these components. First as the cost and the size of the photo detectors were decreasing, the filter and the photo detector were substituted for an array of photo detectors. This reduced the cost of the devices as it was not necessary any scanning device anymore. Later, when it was possible to make photo detectors that were only sensitive to a certain wavelength, the prism and the photo detector array were substituted by an array of photo detectors capable to detect only a certain wavelength. Due to the fact that efficiency of a photo detector depends on the wavelength, among other variables, engineers design the size of the photo detector depending on that. That is why blue photo detector is bigger that red. All these technology advances allow low cost spectrophotometers with a low cost (around 60$), a high level of integration (8cm x 5cm x 3cm), without mobile parts.

All these devices need of a calibration step where they measure a known reference, ideally a perfect reflecting diffuser, and compensate for any unexpected drift. Typical sources of errors compensated at this step are light power from the radiating source, variations with temperature, distance from paper (sample) to sensor and gains for any wavelength.

In this project, we decided to use a Spectrolino from Gretag MacBeth® that was lately absorbed by X-Rite®.

Figure 4-2 Spectrophotometer Spectrolino from X-Rite

4.1.2. Embedded spectrophotometer sensor

The embedded sensor, photograph included in Figure 4-3, is also designed by X-Rite®. It is the same sensor that they include in their i1, i1iO and i1iSis spectrophotometers. In fact, moreover the sensor itself, there is an in-box microcontroller to make it work as an independent device that provides an I^2C[23] interface to work with it.

This microcontroller is also in charge of processing the signal to convert between spectral data and XYZ tristimulus or CIE Lab, and it also takes care of the self calibration algorithm that the sensor does.

[23] Inter-Integrated Circuit, is a multi-master serial single-ended computer bus invented by Philips that is used to attach low-speed peripherals to a motherboard. This protocol is quite extended in the industry because there are no licensing fees are required to implement it.

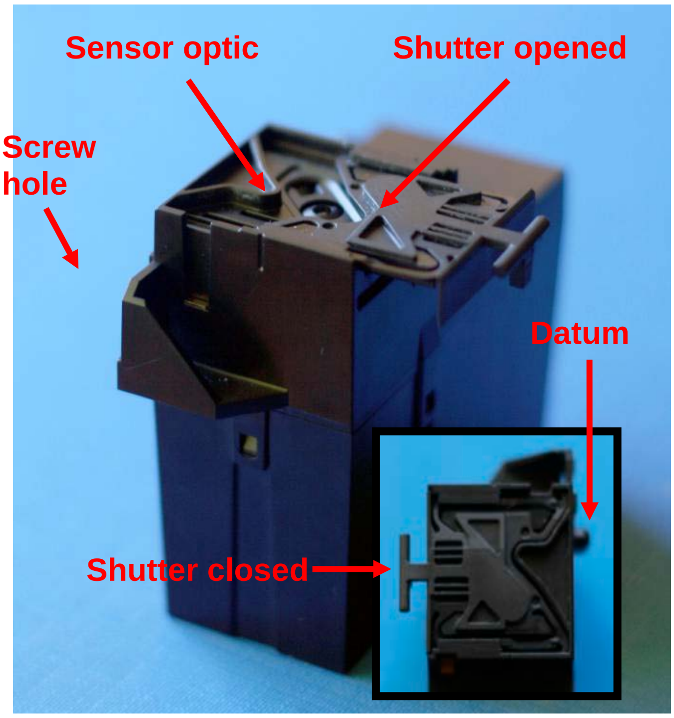

Figure 4-3 Embedded spectrophotometer

In the upper photograph, Figure 4-3, you can see that the spectrophotometer has a shutter that can be open or closed depending on the situation. There is a dedicated section to describe this part and the need that justify it at section 4.2.3.3 Calibration tile and optics dirtiness in page 84. It is important to pay attention to the datum system (there are another datum that cannot be seen because the image is cropped) that ensures the correct assembly of this part to the printer carriage.

In Figure 4-4 Embedded spectrophotometer (detailed view) , is a zoom-in of the sensor with the shutter removed. That view allows us to see the LED used as a light source. It is a white LED whose spectrums peaks and non uniformities are compensated at the calibration stage.

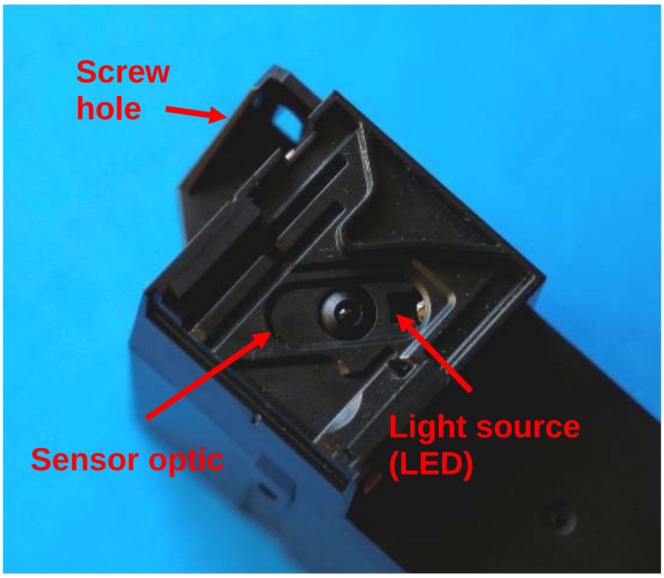

Figure 4-4 Embedded spectrophotometer (detailed view)

Finally we can take a look inside it, in Figure 4-5. It is interesting to see that this is the latest generation on spectrophotometers. It has a grating mirror, a photodiode array and a white led as light source without any mobile part.

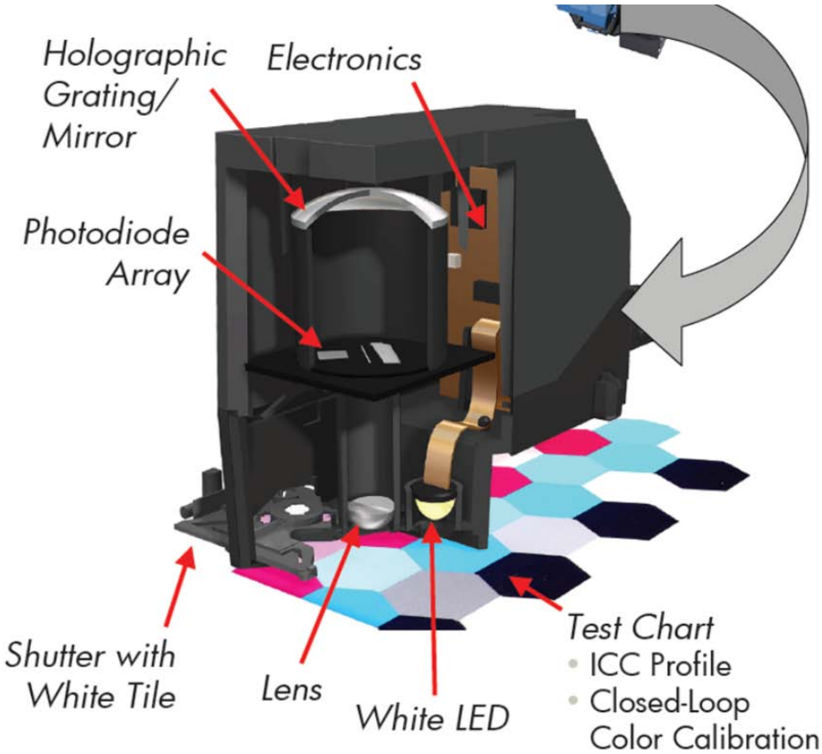

Figure 4-5 Embedded sensor (Inside)

4.1.3. Measurement error sources

4.1.3.1. Calibration offset

As in all measuring devices, we are going to study the repeatability of the measurement. In the next figure we show ten repetitions of the measurement of HP Premium ID Photo Gloss Paper.

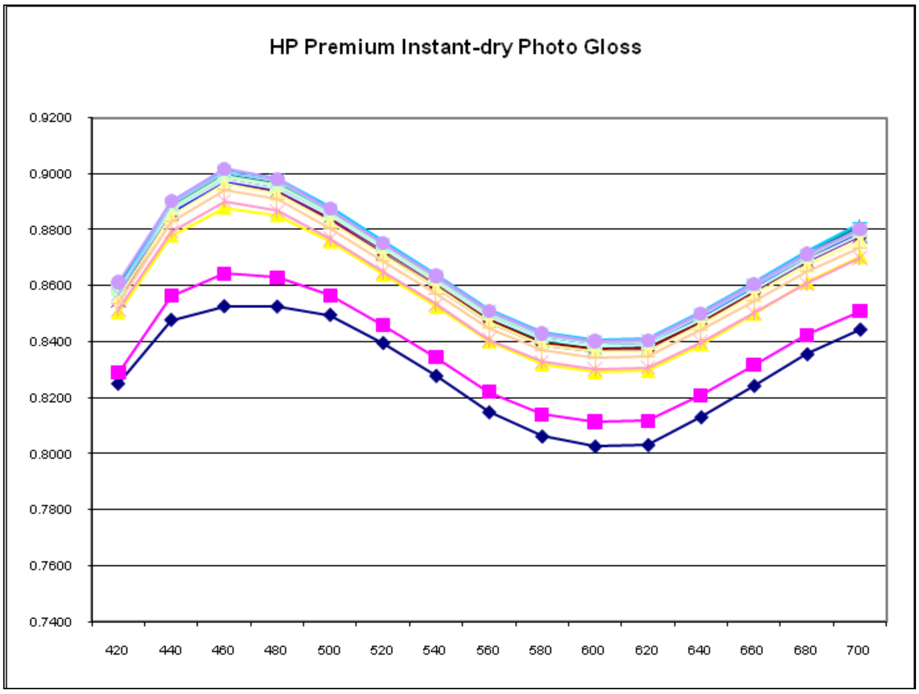

Figure 4-6 Spectrophotometer repeatability

In this case we can see how the shape of the signal is always the same while there is an offset for each measurement.

If we call R the measured reflectance, I the illuminant spectrum, P the substrate reflectance, S the sensor sensitivity, N an additive white noise and Off the offset error, we can write the equation:

$$[R_{420}, R_{440}, \dots, R_{700}] = [I_{420}, \dots, I_{700}] \cdot * [P_{420}, \dots, P_{700}] \cdot * [S_{420}, \dots, S_{700}] + \\ +[N_{420}, \dots, N_{700}] + [Off_{420}, \dots, Off_{700}] \quad (45)$$

* Element by element product also known as dot product.

But if the calibration has worked and the offset error *Off* is the same for all wavelengths ($Off_{420} = Off_{440} = Off_x$), we can ensure that:

$$[I_{420}, \dots, I_{700}] \cdot * [S_{420}, \dots, S_{700}] = \vec{1} \quad (46)$$

$$[Off_{420}, Off_{440}, \dots, Off_{700}] = Off * \vec{1} \quad (47)$$

And finally if we make a relative measurement, we can get rid of the offset error Off.

$$R_{460} - R_{420} = P_{460} + N_{460} + Off_{460} - P_{420} - N_{420} - Off_{420} =$$
$$= (P_{460} - P_{420}) + (N_{460} - N_{420}) \quad (48)$$

And that is true considering that reflectance values $Px >> Nx$, which is true when measuring a blank paper.

$$R_{460} - R_{420} \approx (P_{460} - P_{420}) \quad (49)$$

This result seems to be very robust against measurement noise.

As this measurement is the reflectance factor for each wavelength, people may expect them to be in the range 0 to 1. While this is generally true, because it is not possible to have a reflecting diffuser better than the perfect reflecting diffuser, there is an exception. Many papers can have fluorescent whitening agents that absorb energy from the ultraviolet (aka UV range) and reemits in the visible spectrum normally near the 460nm area. That's the reason that explains why there can be measurements greater than 1.

4.1.3.2. Repeatability

Once the offset has been compensated, Figure 4-7, we can see that the sensor is very repeatable. Although it is difficult to see there are 16 repetitions superimposed of the measurement of HP Instant-Dry photo gloss paper. There are only two measurements that can be considered as erroneous, the ones corresponding to the first and second measurement, so we conclude that maybe the sensor was not well stabilized before start measuring.

Another important learning is that there is not any wavelength worse that other. All of them have a very similar standard deviation of 0.0009. These are really good news as we can have great confidence on this sensor and its measurements.

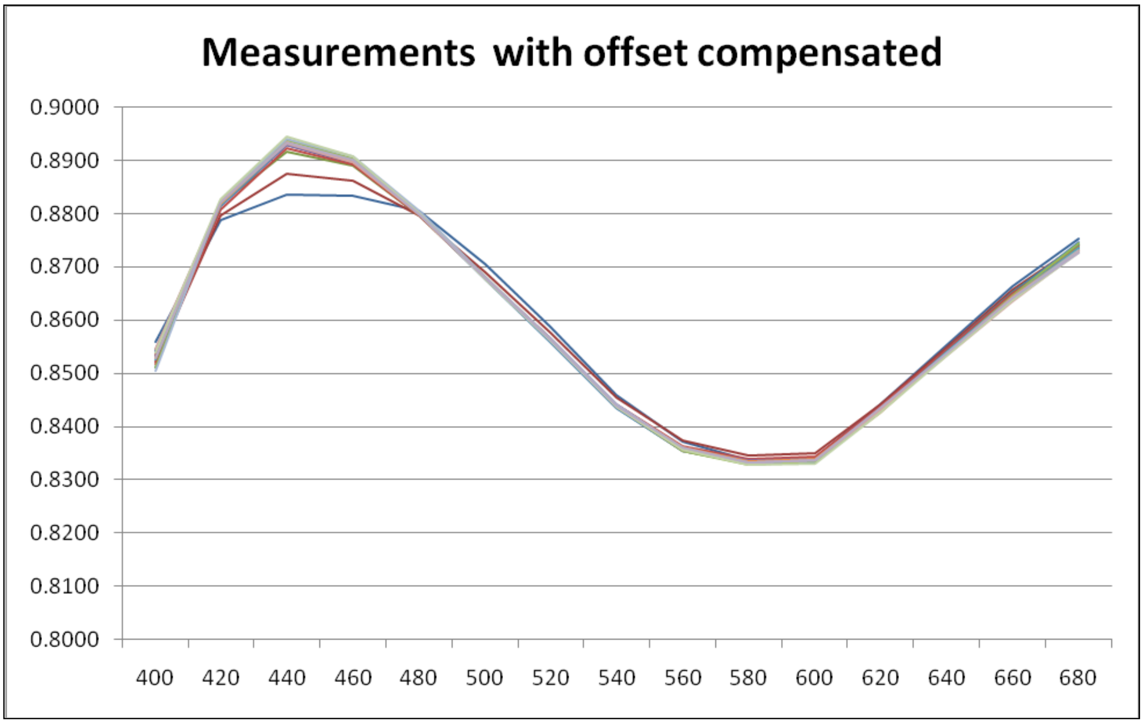

Figure 4-7 Spectral measurement with offset compensation

4.1.3.3. Calibration tile and optics dirtiness

In Figure 4-7 is possible to see the calibration tile mounted on the shutter. That means that it is necessary to have it closed during calibration and open when scanning colors.

This calibration tile has a very smart design patented by X-Rite®. It can be appreciated that it has a trapezoidal shape with the inner part made of transparent plastic material wrapped by a white plastic layer except in the two extremes. The white plastic is used as a perfect reflector (it does not modify the illuminant spectrum) while the inner part is intended to drive the light from the illuminant to the sensor. The number of reflections and the total distance that the light travels inside the trapezoid emulates the real paper to sensor distance.

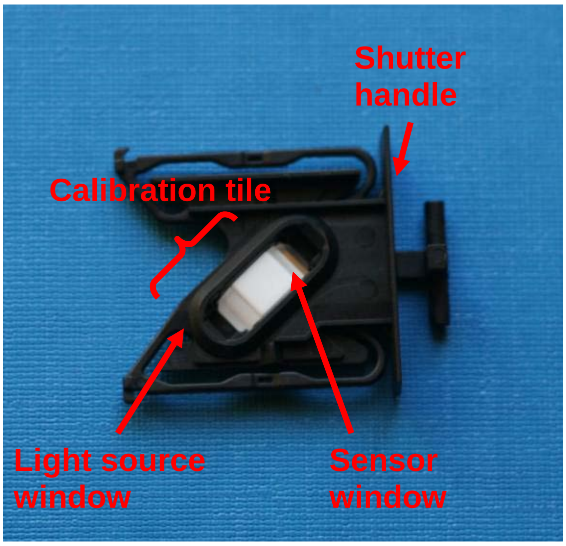

Figure 4-8 Embedded spectrophotometer calibration tile + shutter

This sensor is very sensitive to dirtiness. In previous revisions it was found that aerosol[24] was deposited both on the sensor lens and in the calibration tile. The results where that the aerosol tinted the light (in case of dye inks) or absorbed certain wavelengths (in case of pigmented ink) modifying the illuminant spectrum therefore breaking the calibration. In fact the calibration in these conditions actually uncalibrates the device, and that turns out color measurement erroneous. As a result of that, a new shutter was designed to prevent aerosol to access the tile and the lens. It was also a good idea to have the tile embedded in the sensor because it only needs one shutter to protect both parts.

4.1.3.4. Field of view (FOV)

There is a further explanation of this issue in the Gloss Meter, Field of view (FOV) section at page 95. The principles of the measurement error are the same although it has a bigger impact in the spectrophotometer sensor. In the same manner than the gloss meter, increasing the distance or changing the angle respect to the paper is seen as an attenuation stage, in this case equally for all the wavelengths. For our purposes this is correct while it keeps the original ratio.

[24] Tiny particles of ink generated when printing that can be suspended inside the printer and get attached to plastic and electronics parts.

In case of a color measurement it is not only important to preserve the ratio between the wavelengths but also the absolute magnitude. Otherwise the signal processor computes the CIE Lab color value from an attenuated spectrum and is translated in darker colors.

4.1.4. Differences with Spectrolino and embedded spectrophotometer

There are a few differences between the Spectrolino sensor and the embedded spectrophotometer. The embedded spectrophotometer light source does not emit in the UV range, the wavelength interval is from 420nm to 700nm in 20nm steps instead of 380nm to 730nm in10nm steps. Another important difference is that while the Spectrolino contacts the media surface to make the measurement ensuring that the distance from the media to the sensor is always the same, the embeds spectrophotometer passes over the media without touching it. In this case we cannot ensure that the media is always at the same distance or with the same angle. All that justify why there is more noise from one device measurement to the other.

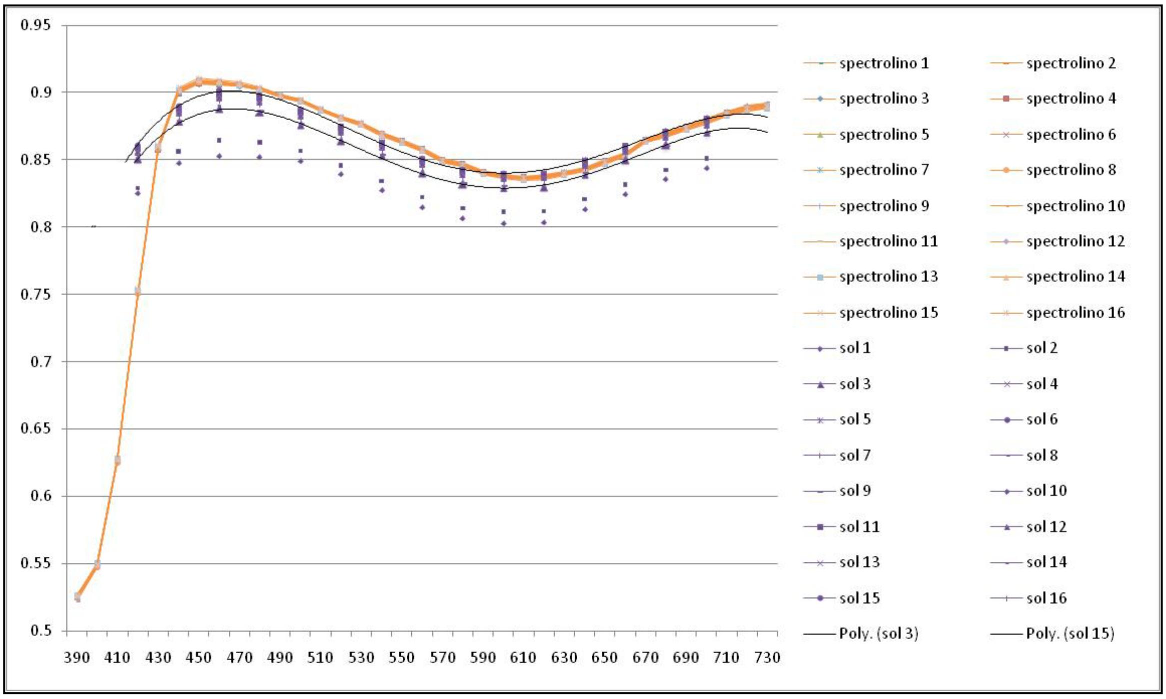

Figure 4-9 Embedded spectrophotometer Vs Spectrolino

Finally in Figure 4-9 we can see graphically all the mentioned differences. In orange there are sixteen measurements done with a Spectrolino. It is so accurate that it seems to be only one measurement. On the other hand, in purple we have sixteen repetitions done with the embedded spectrophotometer. If we eliminate the two erroneous series, we see that it keeps having more variability (variability area marked with the two black lines.

As a conclusion we can say that the Spectrolino is more robust in the calibration stage (less offset error), is more repeatable and we assume that it is more accurate. By the way we can also conclude that both sensors have a very good correlation between them.

It also seems that Spectrolino consistently measures more signal in the 440-510nm range. we do not think that it is related with sensitivity at these frequencies as it would be compensated during the calibration. Instead we think it is more related with the light source with UV + UV filter is not exactly the same than non-UV light.

Finally we include a table with a comparison of a few specs.

	Embedded spectrophotometer by X-Rite	X-Rite ™ i1®
Spectral Range	400 – 700 nm	380 – 730 nm
Spectral Bandwidth	20nm	10nm
Colorimetry	CIELAB, CIE XYZ, spectral, Density Status E	CIELAB, CIE XYZ, spectral, Density Status E, T
Illumination	White LED (UV-cut)	Gas-filled tungsten (A)
Calibration	Integrated white reference	External white reference
Spectral analyzer	Holographic grating, diode array	Holographic grating, diode array
Sensor Accuracy	avg. < 1.1dE94, max < 2.1dE94	N/A
Single Sensor Repeatability	avg. < 0.1dE94 on white reference	avg. < 0.1dE94 on white reference
Sensor-to-Sensor Repeatability	avg. < 0.4dE94 on BCRA tiles	avg. < 0.4dE94 on BCRA tiles

Table 11 Embedded sensor specs

4.2. GLOSS METER

4.2.1. Theoretical description

A gloss meter is a device used to measure the reflection factor from materials at different angles. The difference with spectrophotometers is that while spectrophotometers have an integration sphere to measure the reflectance factor for the average of all angles classified by wavelength the gloss meter gives one reflectance factor for the average of all wavelength classified by angle.

Based on the reflection factor profile of the paper, they can be classified in matte (also called non-gloss), semi-gloss or high gloss. An example of these profiles can be found in Figure 4-10.

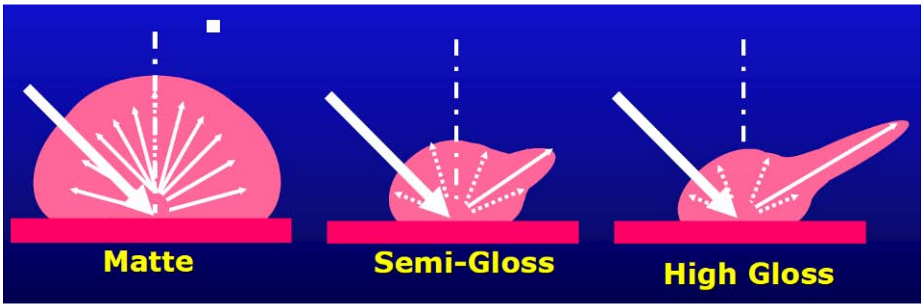

Figure 4-10 Gloss profiles for matte, semi-gloss and high gloss

The main components of a gloss meter are a source of optical radiation, and a mobile photo receptor or array of photo receptors. It is wide extended to measure two of the standard geometries, where the first position is the emitter angle and the second is the sensor angle, 45/Normal and 45/45. In the following illustration we can see a diagram of a gloss meter.

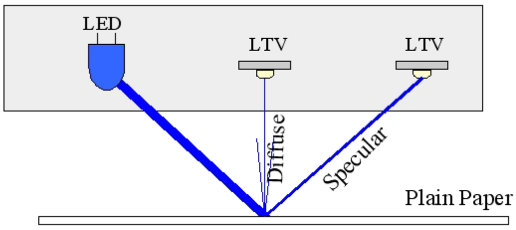

Figure 4-11 Gloss meter parts

Based on the principles of this sensor, it does not need to be calibrated. The change on the light source is affecting both sensors. As we want the ratio of them, it should be independent of the power of the illuminant.

$$P_{specular} = P_{led} * R(90^{\circ}) \quad (50)$$

$$P_{diffuse} = P_{led} * R(45^{\circ}) \quad (51)$$

$$Reflectance\ \ ratio = \frac{P_{specular}}{P_{diffuse}} = \frac{R(90^{\circ})}{R(45^{\circ})} \quad (52)$$

In this project, we decided to use a micro-TRI-gloss from BYK-Gardner to prototype the algorithm. This handheld device is able to measure the gloss in three angles 20º, 60º and 85º.

Figure 4-12 Micro-TRI-gloss from BYK-Gardner

4.2.2. Embedded gloss meter sensor

In this section we are going to show some photographs of the embedded sensor. We have to keep in mind that it was not designed to measure gloss levels. So, we do not expect to get measures following any standard but just analyze the signal detected from many papers and process it in a manner that helps for our purposes.

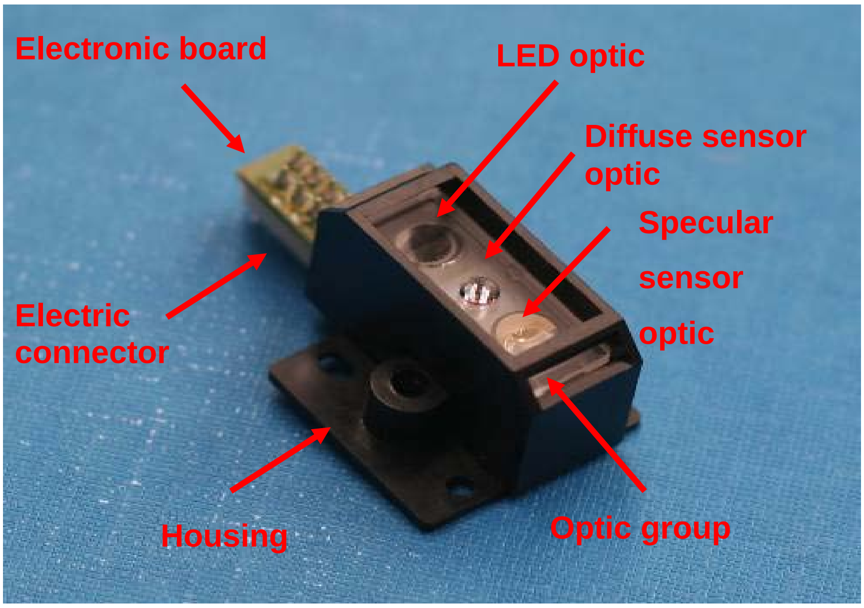

Figure 4-13 Embeded gloss meter (Outside)

The two-sides electronic board, which can be seen in the next figure, holds all the electronic components as sensors, LEDs, accessory circuitry... The connector holds the trailing cable used to communicate the sensor with the printer. The optic group focuses the light in a spot on the paper and concentrates again this area in the sensor sensitive area. Finally the housing has to important functions, it ensures the correct assembly position using a datum system, and it protects the sensor from paper crashes.

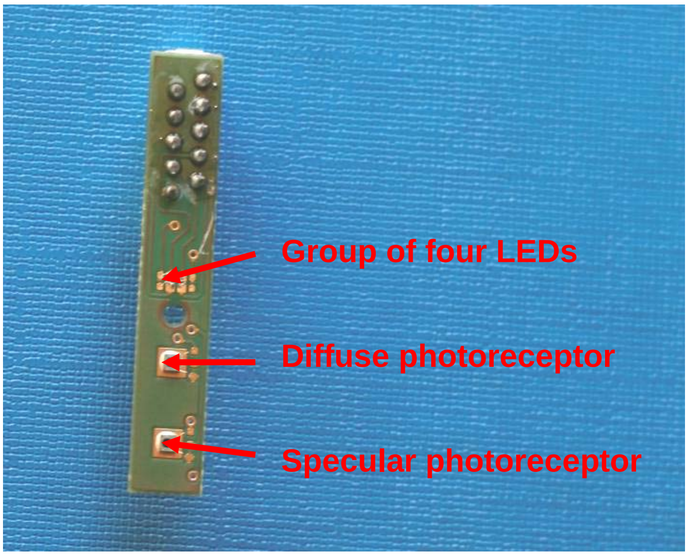

Figure 4-14 Embedded gloss meter (Inside)

In Figure 4-14 it is possible to see both photoreceptors (specular and diffused). There are also four tiny spots which are actually LEDs[25]. All the components are SMC[26] to save space. In the other side of the board, there is the electric connector and a small IC that contains a small NVM[27] to save all the line calibrations, an I^2C (Inter-Integrated Circuit) communication protocol interpreter, an A/D and D/A to read the sensor and drive the LED respectively and some auxiliary circuitry.

4.2.3. Measurement error sources

4.2.3.1. Temperature effect

It is well known that LED emitters are less efficient when they are hot. The following figure, Figure 4-15, shows an experiment done to find how long does it takes to warm-up a LED driven at different currents. On the left axis we have digital counts from the A/D converter in the range 0-1023. Each repetition has been done with a different LED current value. We can see how the receptor is saturated for the first trial and for the first 0.5s of the second trial. We have waited two hours between each repetition in order to let the emitter get cold. Based on this data we could compensate this effect but it would be a long investigation. For our purposes we recommend to wait a warm-up time of 2s and take all the measurements in an interval shorter than 250ms.

[25] Light Emitting Diode
[26] Surface Mount Technology
[27] Non Volatile Memory

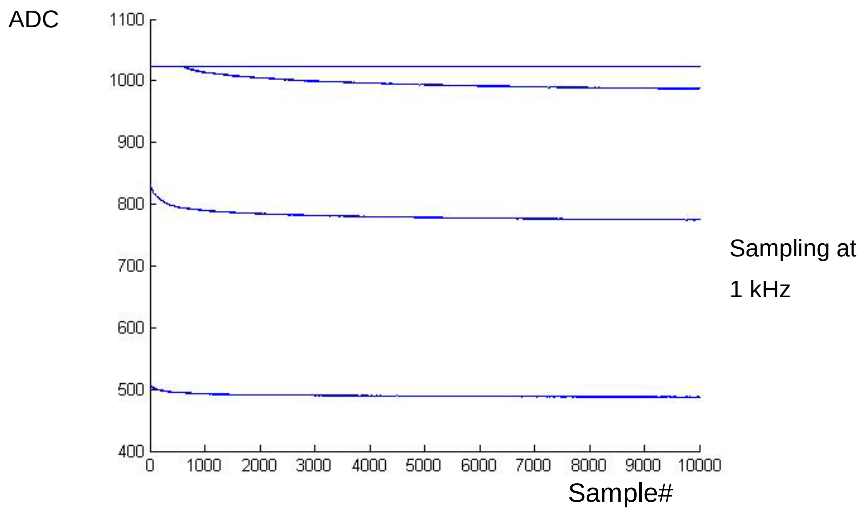

Figure 4-15 Signal variation with time (temperature)

4.2.3.2. Wavelength drift

Another temperature effect is that the LED slightly changes the wavelength where it emits. In our case this second effect is not an issue because this change is small enough to ignore it and because white paper spectrum is quite continuous whit small variations for near point.

In the next table there are the specifications for the wavelength range that we could expect for a LED.

Parameter	Conditions	Min	Max	Unit
Dominant wavelength, Blue	IF = 20 mA	465	475	nm
Dominant wavelength, Green	IF = 20 mA	525	535	nm
Dominant wavelength, Orange	IF = 20 mA	600	610	nm
Dominant wavelength, Red	IF = 20 mA	625	635	nm

Table 12 Dominant Wavelength by LED

While this can be an issue to measure color, it is not to measure the blank paper. This is due to the fact that all papers are designed to be white (except special applications) and bright. The ideal paper would reflect the same amount of light (and the maximum possible) for all the wavelengths. And that means that the light reflected for two similar wavelengths is similar.

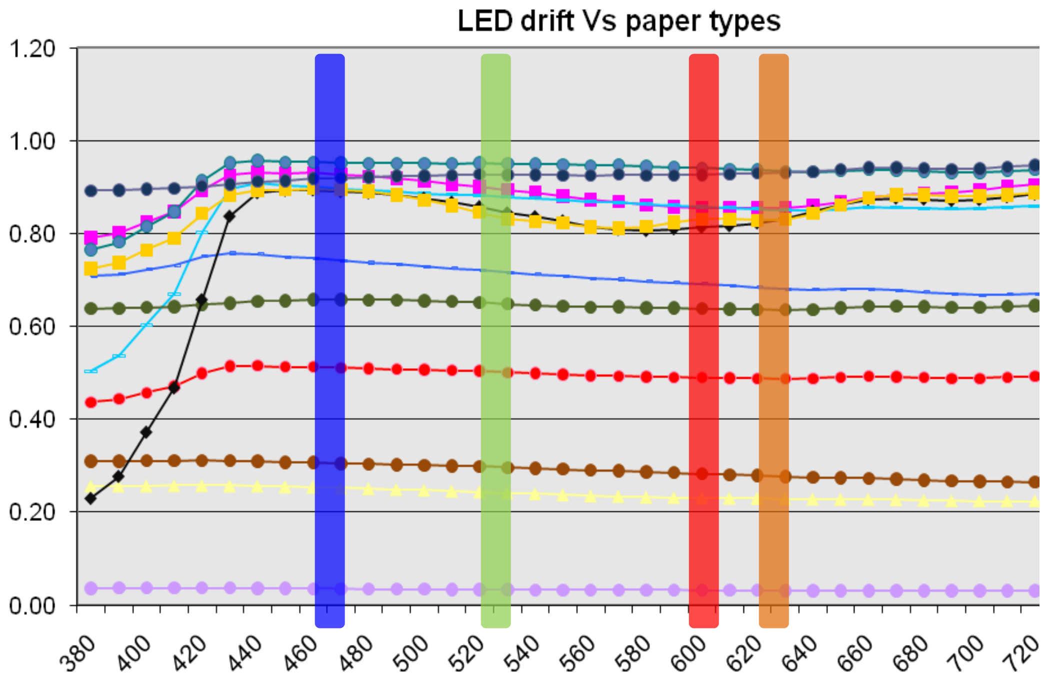

Figure 4-16 LED drift impact

In the Figure 4-16 there are represented the spectrum of a brunch of representative papers. Over this graph we have superposed a colored box representing the possible wavelength range for each of the LEDs that has our sensor. As you can see there are small changes of the spectrum in each of the areas of interest.

4.2.3.3. Different sensor gain

Due to the fact that we have two different sensors for the two angles measured, we have to deal with the different gain of each of them. In the following figure we have measured the signal captured with both channels for different values of current in the LED. There are several takes away from this chart. The most important is that each sensor may have a different gain. The second one is to identify a safe work area for our gloss meter. If we analyze the non linearity zones seen in the graph we can identify two areas. The first one marked with an orange ellipse is due to the residual illumination coming from external light sources. So, when the LED is working at low currents, the environmental illumination can be greater than the LED. The second non linearity has been marked with a blue ellipse. This effect is due to the saturation of the sensor. For this specific sensor we can conclude that it gets saturated at 900 ADC counts.

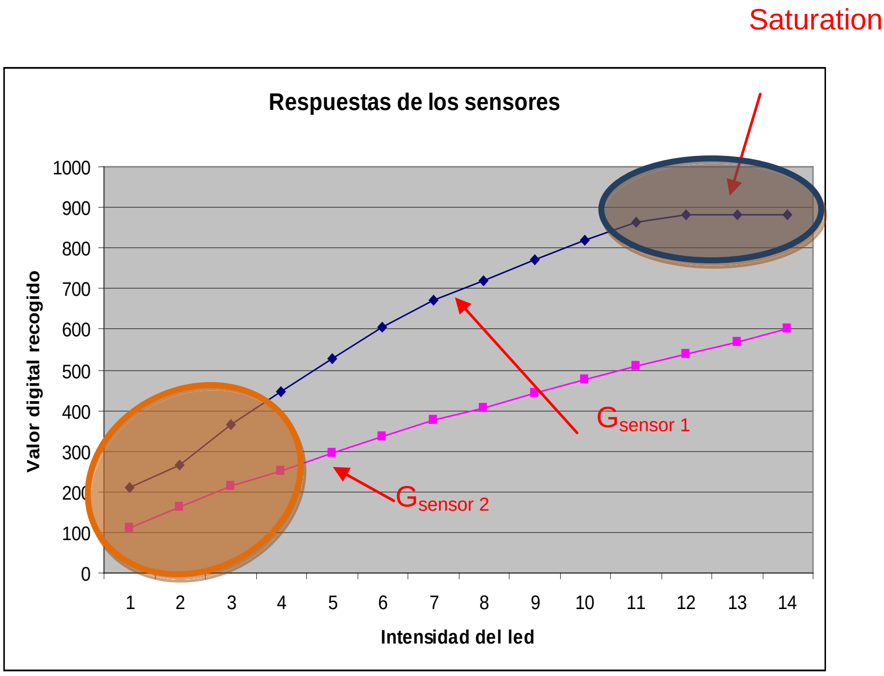

Figure 4-17 Gloss meter sensors response

Ideally this gain differences should be calibrated. This can be included in the production line where it is necessary to measure a perfect reflector as a reference and compute the gain of each sensor. Once the gloss meter is calibrated, we can assume that the residual error is small enough to be ignored.

$$P_{specular} = P_{led} * R(90^{\circ}) * (G_{nominal} + E_{specular}) \quad (53)$$

$$P_{diffuse} = P_{led} * R(90^{\circ}) * (G_{nominal} + E_{diffuse}) \quad (54)$$

Assuming that the production line calibration has worked $Gnominal >> Especular$ and E $diffuse$.

$$Reflectance\ ratio = \frac{P_{specular}}{P_{diffuse}} = \frac{R(90^{\circ})}{R(45^{\circ})} + Error \quad (55)$$

4.2.3.4. Optics dirtiness

One of the problems of embedding a sensor in a printer is how to keep it clean. The printing platen is a dirty environment where there are ink particles that can lay on the surface of the sensor or its optic group. In the next photograph we can see tiny drops of ink that have reached the surface of the lens.

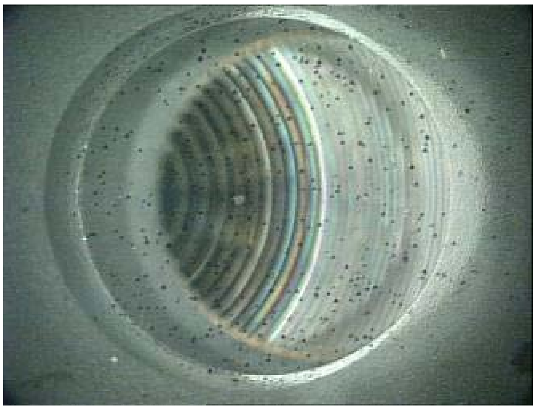

Figure 4-18 Dirtiness in the optic

While this can be a problem for other sensors, it is not the case for the gloss meter. Usually it is used to detect edges of the media or in alignment calibrations where we look for binary signal (true or false) and not to take absolute measurements (sensitive to attenuations). That means that even we know the dynamic range of the sensor is reduced, we keep on being able to get enough signal to distinguish between the 0 condition and the 1 condition. In our particular case where we study the absolute measurement, we are fortunate to have two channels (specular and diffuse) and employ a ratio that makes the measurement power independent. If the optic gets dirty, it is for the LED and for both channels. This is true if the optic get uniformly dirtied which it is a reasonable assumption.

4.2.3.5. Field of view (FOV)

In this section, we will explain in depth the concept of FOV of the embedded gloss meter sensor under different input variables. A part from FOV size we were interested in the shape of the FOV. In a first approach, the expected field of view of the sensor is a circular shape on the paper. Due to different reasons this can be different and we can find several possibilities. In Figure 4-19, there are represented the possibilities. It is easy to understand that the LED plus the lens emits the light in a cone that intersects the paper. Then if the media is perpendicular to the cone we will get a circular shape and if it is not, we will get an ellipsoid.

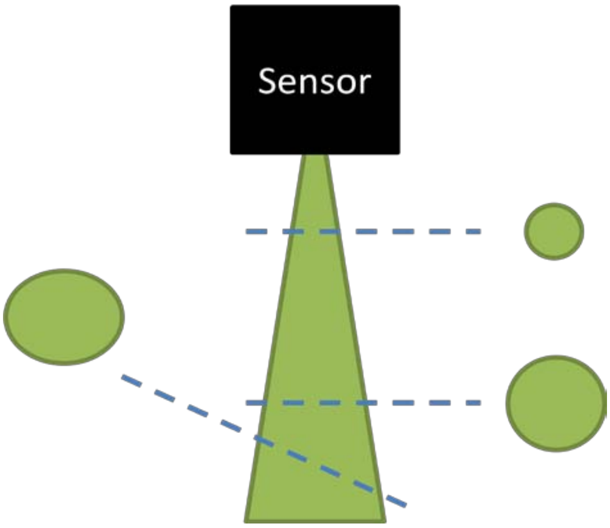

Figure 4-19 FOV possible shapes

We can deduce that a change in the distance between the paper and the sensor has an impact in the size of the shape while a change in the angle turns the circle in an ellipsoid (note that this ellipsoid can vary in both axes and is not limited to the proposed example). It is important to understand that this error in the angle can come from the mounting position of the sensor in the carriage or from a misplacement of the paper.

Finally the question is how does this affect to the measure of the gloss meter? The answer is that we get more or less signal (it is like an attenuator). The closer and the better aligned the media is, the greater the signal that we get. Light gets scattered in all directions, so if media is far away or is misaligned, there are much light that will be loosed and not measured.

4.2.4. Differences between micro-TRI-gloss and embedded gloss meter

There are three main differences between these two devices. The first on is that while micro-TRI-gloss can measure 20º, 60º and 85º the embedded gloss meter can only do it at 45º and 90º. The second difference is the light source. The embedded gloss meter uses four LED (blue 460nm, green 520nm, orange 610nm and red 650nm) while the micro-TRI-gloss uses a white LED to cover the full spectrum. The third difference is again with the distance from the paper to the sensor and its angle. In the micro-TRI-gloss handheld device, the measurement is done in contact with the paper and with the device aligned perpendicular to the paper. In the embedded gloss meter, this distance may have variations and the angle respect to the media can change.

4.3. SUMMARY

In this chapter we have seen the two kinds of sensors that we are going to use to perform the automatic identification of the media type. It has been covered how they work, a commercial version of them and the differences with the embedded sensors that we have available.

We have also gone through the challenges of embedding systems in a printer, ensuring the assembly position and protecting from the not friendly environment inside the printer.

It is very important to understand the error sources in order to define the testing environment to get valid data.

5. DATA ANALYSIS

In this chapter we will introduce the C_{pk} concept and the six-sigma methodology as a vehicle for our purposes. Based on all that, we present the analysis of the different properties independently that faces us to the impossibility to identify correctly the media by using only one of them. Our proposal will be an analysis workflow and the optimal thresholds to make this identification possible.

5.1. CPK METHODOLOGY

The C_{pk} is known as the process capability index or process capability ratio and it is a statistical measure of process capability widely used in process improvements efforts. By definition it is the ability of a process to produce an output within specification limits. The concept of process capability only holds meaning for processes that are in a state of statistical control. Process capability indices measure how much "natural variation" a process experiences relative to its specification limits and allows different processes to be compared with respect to how well an organization controls them.

If the upper and lower specification limits of the process are USL and LSL, the target process mean is T, the estimated mean of the process is μ and the estimated variability of the process (expressed as a standard deviation) is σ, then commonly-accepted process capability indices include:

$$\hat{C}_p = \frac{USL-LSL}{6\hat{\sigma}} \quad (56)$$

$$\hat{C}_{p,lower} = \frac{\hat{\mu}-LSL}{3\hat{\sigma}} \quad (57)$$

$$\hat{C}_{p,upper} = \frac{USL-\hat{\mu}}{3\hat{\sigma}} \quad (58)$$

$$\hat{C}_{pk} = min\left[\frac{USL-\hat{\mu}}{3\hat{\sigma}}, \frac{\hat{\mu}-LSL}{3\hat{\sigma}}\right] \quad (59)$$

The mapping from process capability indices, such as Cpk, to measures of process fallout is straightforward. Process fallout quantifies how many defects a process produces and is measured by PPM[28]. Process yield is, of course, the complement of process fallout and is approximately equal to the area under the probability density function

$$\Phi(\sigma) = \frac{1}{\sqrt{2\pi}} = \int_{-\sigma}^{\sigma} e^{\frac{-t^2}{2}} dt \qquad (60)$$

if the process output is approximately normally distributed.

In the short term ("short sigma"), the relationships are:

Cpk	Sigma level (σ)	Area under the probability density function ϕ(σ)	Process yield	Process fallout (PPM)
0.33	1	0.682689492	0.6827	317311
0.67	2	0.954499736	0.9545	45500
1	3	0.997300204	0.9973	2700
1.33	4	0.999936658	0.9999	63
1.67	5	0.999999427	0.999999	1
2	6	0.999999998	0.999999998	0.002

Table 13 Cpk, σ-level and process fail rate

In the long term, processes can shift or drift significantly (most control charts are only sensitive to changes of 1.5σ or greater in process output), so process capability indices are not applicable as they require statistical control.

5.2. PAPER WHITE POINT

5.2.1. Introduction

In this section we are going to analyze the CIE $L^*a^*b^*$ colorimetric value of each blank paper, known as white point. This measurement, as it was presented in the CIE $L^*a^*b^*$ color space section, is obtained from the absolute values of the spectrum of the paper surface. That means that it is not robust to many of the effects that we have seen for the spectrophotometer and that is translated in higher variability.

[28] Parts Per Million

In order to keep it simple we have split this analysis in two parts, L^* and a^*b^*.

5.2.2. Lightness study (L^*)

In this section we are going to do an analysis on the lightness measurement, its pros and also its cons. To do it we have measured sixteen times each paper. As a result we have calculated the average lightness and its standard deviation. Using the 3σ methodology we have computed the range in the measurement that each paper may have for 94% of cases. In Table 14, there is the compilation of this data.

	Avg L*	L* stdev	Avg - 3σ	Avg + 3σ
HP Professional Matte Canvas	96.86	0.187	96.30	97.42
HP Hahnemühle Textured Fine Art Paper	96.07	0.181	95.53	96.61
HP Hahnemühle Smooth Fine Art Paper	95.80	0.155	95.33	96.26
HP Artist Matte Canvas	95.49	0.215	94.85	96.14
HP Matte Litho-realistic Paper	95.47	0.044	95.34	95.60
HP Professional Semi-gloss Contract Proofing Paper	94.21	0.148	93.77	94.65
HP Collector Satin Canvas	94.18	0.327	93.20	95.17
HP Premium Instant-dry Photo Satin	94.06	0.105	93.74	94.37
HP Premium Instant-dry Photo Gloss	93.88	0.322	92.91	94.84
HP Proofing Matte	92.92	0.326	91.94	93.89
HP Professional High-gloss Contract Proofing Paper	92.91	0.159	92.44	93.39
Super Heavyweight Coated Paper	92.60	0.087	92.34	92.85
HP Universal Instant-dry Photo Gloss	92.42	0.220	91.76	93.08
HP Bright White Inkjet Paper	92.11	0.318	91.16	93.07
HP Heavyweight Coated Paper	92.10	0.263	91.31	92.89
HP Coated Paper	90.35	0.384	89.20	91.50
Translucent Bond	83.12	0.635	81.21	85.02
Vellum	72.97	0.466	71.57	74.37
Matte Film	59.38	0.150	58.93	59.83
Natural Tracing Paper	52.47	0.539	50.86	54.09
Transparent/Clear Film	14.38	2.331	7.38	21.37

Table 14 L analysis*

The main problem with this metric is that all papers have the same design objective for lightness. All of them try to obtain the maximum lightness level because, it is very important for color gamut and it is detected very easily for customers that see brighter papers as better quality.

As a result, we have more that 75% of papers (16 of 21) in the range of 90 – 96 L*. If we look at the expected range of each of them we can see that in this 75% of cases they are overlapped, being impossible to identify which is the specific media.

Just to make the analysis of the results more simple, we have included a chart in Figure 5-1 where it can be checked how most of the medias are in the same L* range and which of them are totally isolated and can be identified.

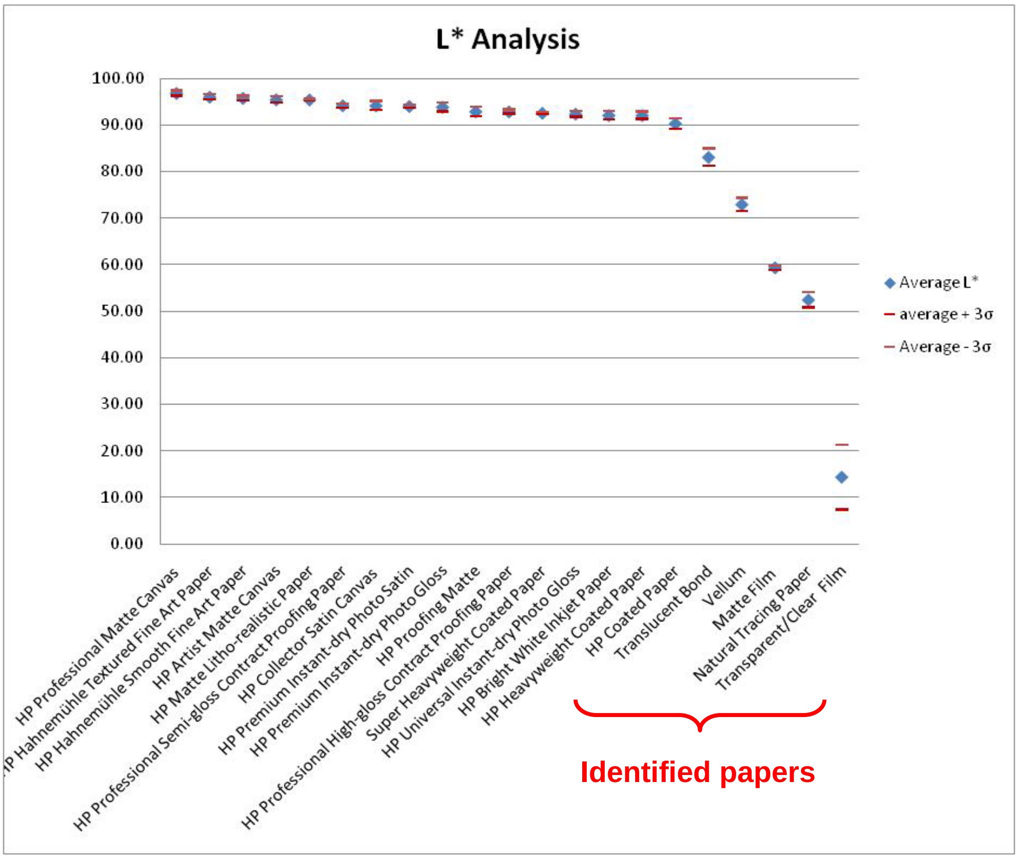

Figure 5-1 L Analysis*

With this method by itself we are only able to distinguish between six families. In the following table there are the results.

Identified Medias

Family 1:	Tech.	clear film
Family 2:	Tech.	natural tracing
Family 3:	Tech.	matte film
Family 4:	Tech.	vellum
Family 5:	Tech.	translucent bond
Family 6:	All	glossy HG / glossy SG / casablanca / plain / proofing matte / coated / HWC / sHWC / canvas satin / canvas artist / professional canvas / prrofing SG / HG proofing / mate litho / smooth FA / texture FA

Table 15 L classification table.*

5.2.3. CIE a^*b^* study

In this case we are going to study the possibility to identify a media type based on the color of its surface. In the Figure 5-2 CIE a*b* measurements for each paper , we can find an a^*b^* plot. Remember that the vertical axis (b^*) means yellow for b^* greater than 0 and blue opposite side and horizontal axis (a^*) means magenta for positive and green for negative values.

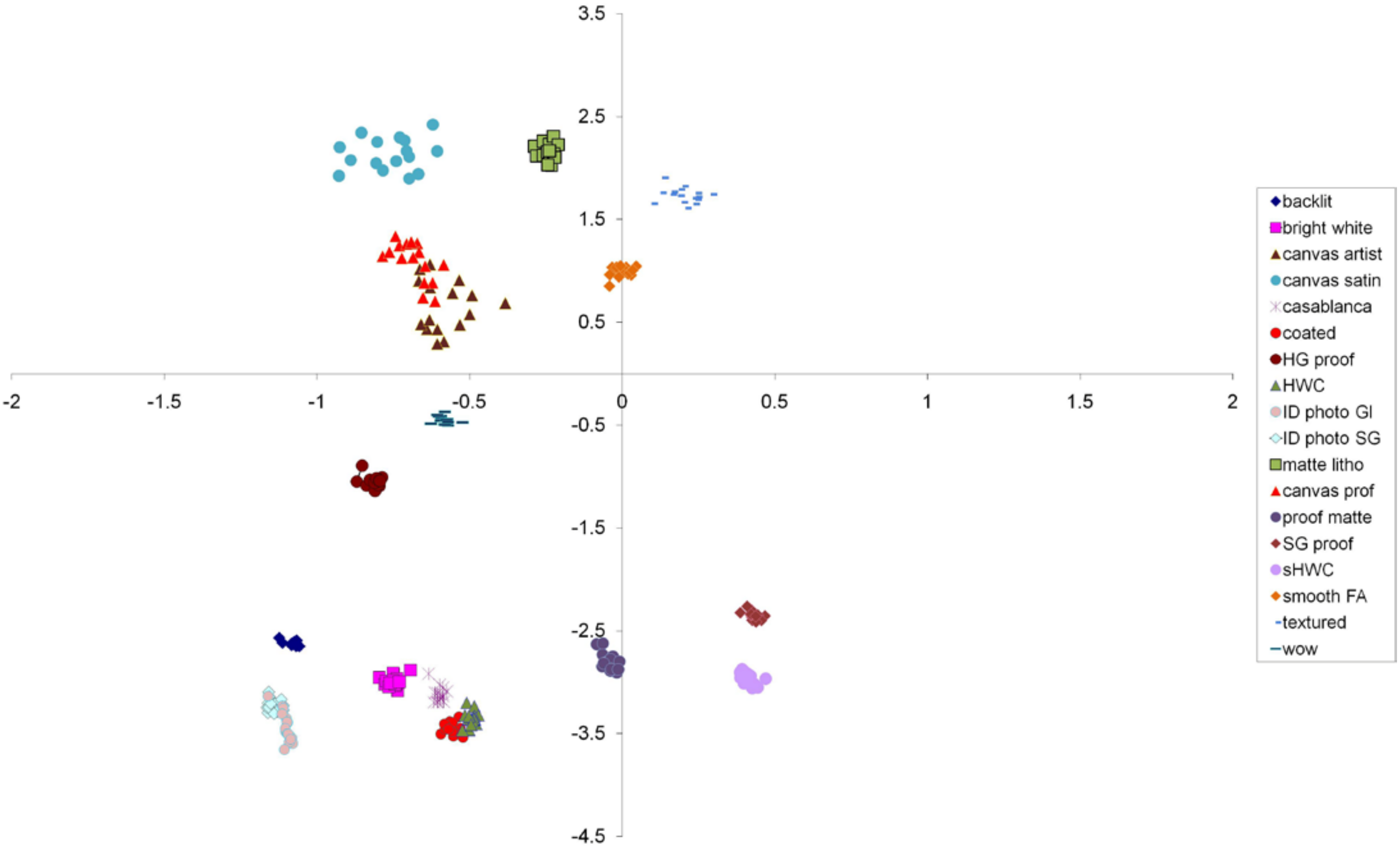

*Figure 5-2 CIE a*b* measurements for each paper*

In this representation we have sixteen measurements of each paper done with the same sensor in the same printer. There are many things that are worth to be commented. It is interesting to point out how fine art and canvas papers (yellowish papers upper area) measurements have more variability due to the texture that they have. Another important take away is how papers that use Shadowing Dyes (SD) have a negative b^* value. Finally it is also interesting to see how papers that have exactly the same coating are not distinguished by this method. As an example, look at coated-HWC, ID photo gloss-ID photo SG or canvas artist-canvas professional. To analyze differences between them, we are going to use the CIE DE76 metric. In the following chart you can find this metrics.

delta E																					
HP Premium Instant-dry Photo Gloss		0.20	1.56	4.86	4.19	3.66	2.85	2.73	1.38	41.41	10.95	20.96	79.51	34.50	3.59	1.95	2.15	2.16	4.96	4.43	4.81
HP Premium Instant-dry Photo Satin	0.20		1.73	4.93	4.12	3.66	2.99	2.79	1.56	41.59	11.14	21.15	79.69	34.68	3.78	2.15	2.32	2.36	4.96	4.43	4.83
HP Universal Instant-dry Photo Gloss	1.56	1.73		5.55	5.54	4.79	3.13	3.56	1.02	39.95	9.60	19.54	78.05	33.05	2.15	1.04	1.45	1.67	6.00	5.48	5.78
HP Collector Satin Canvas	4.86	4.93	5.55		3.31	2.05	2.51	2.18	4.81	42.05	11.44	21.49	79.92	35.18	6.13	4.77	5.25	4.17	2.20	2.03	1.40
HP Professional Matte Canvas	4.19	4.12	5.54	3.31		1.42	3.97	2.66	4.77	44.52	13.78	23.94	82.52	37.62	7.10	5.31	5.28	5.04	1.75	1.52	2.12
HP Artist Matte Canvas	3.66	3.66	4.79	2.05	1.42		2.65	1.42	4.01	43.18	12.45	22.60	81.16	36.28	6.06	4.34	4.54	3.95	1.45	0.93	1.26
HP Professional High-gloss Contract	2.85	2.99	3.13	2.51	3.97	2.65		1.32	2.54	40.56	9.83	19.98	78.56	33.66	3.68	2.30	3.06	1.66	3.69	3.22	3.17
HP Professional Semi-gloss Contract	2.73	2.79	3.56	2.18	2.66	1.42	1.32		2.78	41.85	11.12	21.28	79.86	34.96	4.66	2.98	3.33	2.56	2.58	2.06	2.22
HP Proofing Matte	1.38	1.56	1.02	4.81	4.77	4.01	2.54	2.78		40.46	9.95	19.99	78.54	33.56	2.59	0.96	0.86	1.46	5.11	4.61	4.94
Natural Tracing Paper	41.41	41.59	39.95	42.05	44.52	43.18	40.56	41.85	40.46		30.74	20.58	38.11	6.93	37.88	39.64	40.16	39.68	43.87	43.55	43.28
Translucent Bond	10.95	11.14	9.60	11.44	13.78	12.45	9.83	11.12	9.95	30.74		10.16	68.75	23.85	7.47	9.09	9.74	9.03	13.18	12.83	12.61
Vellum	20.96	21.15	19.54	21.49	23.94	22.60	19.98	21.28	19.99	20.58	10.16		58.60	13.71	17.44	19.15	19.72	19.15	23.29	22.97	22.71
Transparent/Clear Film	79.51	79.69	78.05	79.92	82.52	81.16	78.56	79.86	78.54	38.11	68.75	58.60		45.02	75.97	77.72	78.23	77.74	81.78	81.49	81.18
Matte Film	34.50	34.68	33.05	35.18	37.62	36.28	33.66	34.96	33.56	6.93	23.85	13.71	45.02		30.98	32.74	33.28	32.77	37.00	36.67	36.41
HP Coated Paper	3.59	3.78	2.15	6.13	7.10	6.06	3.68	4.66	2.59	37.88	7.47	17.44	75.97	30.98		1.82	2.49	2.15	7.12	6.64	6.76
HP Heavyweight Coated Paper	1.95	2.15	1.04	4.77	5.31	4.34	2.30	2.98	0.96	39.64	9.09	19.15	77.72	32.74	1.82		1.37	0.75	5.47	4.97	5.17
Super Heavyweight Coated Paper	2.15	2.32	1.45	5.25	5.28	4.54	3.06	3.33	0.86	40.16	9.74	19.72	78.23	33.28	2.49	1.37		1.97	5.49	5.03	5.38
HP Bright White Inkjet Paper	2.16	2.36	1.67	4.17	5.04	3.95	1.66	2.56	1.46	39.68	9.03	19.15	77.74	32.77	2.15	0.75	1.97		5.09	4.60	4.70
HP Hahnemühle Textured Fine Art P	4.96	4.96	6.00	2.20	1.75	1.45	3.69	2.58	5.11	43.87	13.18	23.29	81.78	37.00	7.12	5.47	5.49	5.09		0.54	0.83
HP Hahnemühle Smooth Fine Art Pa	4.43	4.43	5.48	2.03	1.52	0.93	3.22	2.06	4.61	43.55	12.83	22.97	81.49	36.67	6.64	4.97	5.03	4.60	0.54		0.77
HP Matte Litho-realistic Paper	4.81	4.83	5.78	1.40	2.12	1.26	3.17	2.22	4.94	43.28	12.61	22.71	81.18	36.41	6.76	5.17	5.38	4.70	0.83	0.77	

Table 16 CIE DE76 analysis

Based on sensor to sensor accuracy (0.4 DE94) and sensor repeatability (0.1 DE94), we should propose 1DE94 as the threshold to decide whether a paper is identified or not. This is somehow too much optimistic. As an example, if we take a look to the HP Collector Canvas Satin (Table 17), we can compute the average $L^*a^*b^*$ and take it as a reference. Now if we compute all the differences against the reference, we obtain a distribution of the error. Calculating the average and the standard deviation following the 3-sigma methodology we see that the measurement is below 1 DE74 for 94% of cases. That means that we need at least 2DE76 distance between two media to be able to distinguish them.

		L*	a*	b*	DE76
HP Collector Satin Canvas	M1	94.3826	-0.5938	2.3798	0.20273
	M2	93.4463	-0.5718	2.2941	0.740091
	M3	94.0568	-0.6404	2.0302	0.333881
	M4	93.8193	-0.6072	2.2092	0.386875
	M5	94.5004	-0.6193	2.3875	0.320619
	M6	93.7363	-0.5994	2.2320	0.460281
	M7	93.5290	-0.5475	2.4473	0.667087
	M8	94.5441	-0.5192	2.6279	0.469739
	M9	94.2602	-0.5975	2.1523	0.198067
	M10	94.3895	-0.5183	2.5101	0.280331
	M11	94.7387	-0.5727	2.3678	0.555367
	M12	94.6556	-0.6303	2.4835	0.49462
	M13	94.2611	-0.5801	2.4879	0.171209
	M14	93.9466	-0.6356	2.3819	0.245736
	M15	94.5494	-0.6615	2.1717	0.404826
	M16	94.1412	-0.6603	2.2052	0.151278
	Aver	94.1848	-0.5972	2.3355	0.380171
	Std	0.3273	0.0346	0.1317	0.176103

Table 17 Collector Canvas Satin measurements

For our experience in color measurements with the embedded sensor this variability is more in the order of 1.5DE76. The specification of the sensor is under a very controlled environment where all error sources proposed in section Measurement error sources in page 82. That is the reason to select 3DE76 as the threshold.

Finally the classification table for this method will be the same than with L*.

Identified Medias

Family 1:	Tech.	clear film
Family 2:	Tech.	natural tracing
Family 3:	Tech.	matte film
Family 4:	Tech.	vellum
Family 5:	Tech.	translucent bond
Family 6:	All	glossy HG / glossy SG / casablanca / plain / proofing matte / coated / HWC / sHWC / canvas satin / canvas artist / professional canvas / prrofing SG / HG proofing / mate litho / smooth FA / texture FA

Table 18 CIE DE76 classification table

As a conclusion we do not recommend to base the identification algorithm on these techniques. They do not offer enough resolution by themselves and are very prone to errors on the degradation of the sensor because they are based on absolute measurements instead of relative.

However, there are five substrates that seem to have enough signal level to be identified by this methodology. Just in order to reduce the complexity of the problem, we can consider it as resolved avoiding the analysis in the next proposed methods.

5.3. SPECTRUM

5.3.1. Introduction

To make the analysis on the substrate spectrum it is interesting to look at the next figure extracted from a paper written by Ole Norberg from Mid Sweden University, which is included in the bibliography ref[7]. In this paper Mr. Norberg explains how paper whiteness affects color reproduction. In our case the most interesting part is the effects of Fluorescent Whitening Agents (FWA) and Shadowing Dyes (SD) on the substrate spectrum shape.

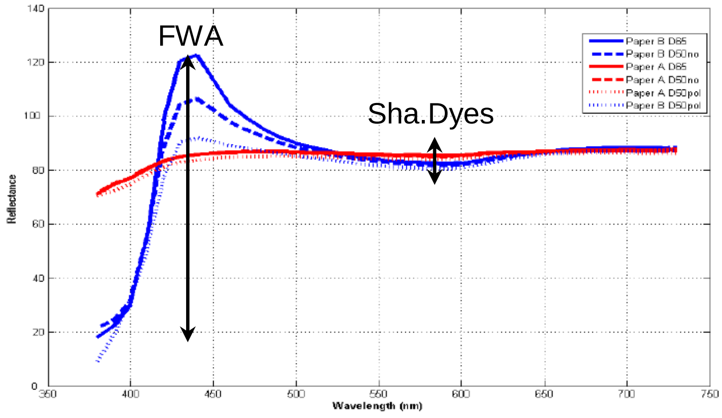

Figure 1: The effect of fluorescent whitening agent (FWA) and shading dyes for different light sources, D65 solid lines, D50 dashed lines and low UV content dotted lines. Paper A does not include any FWA or shading dyes while paper B is representative to a commercial office paper. Notice the large difference in reflectance for paper B (blue lines) while the reflectance spectra of paper A (red lines) are unchanged. The FWA absorb UV light below 400nm and re-emits light around 425nm. The shading dye absorbs light between 550nm and 650nm.

Figure 5-3 FWA and SD effect

Following this hint, we measured the spectrum of the whole media set with the Spectrolino. As a result you can look at Figure 5-4. This is a very interesting result because there is a clear signal in both regions.

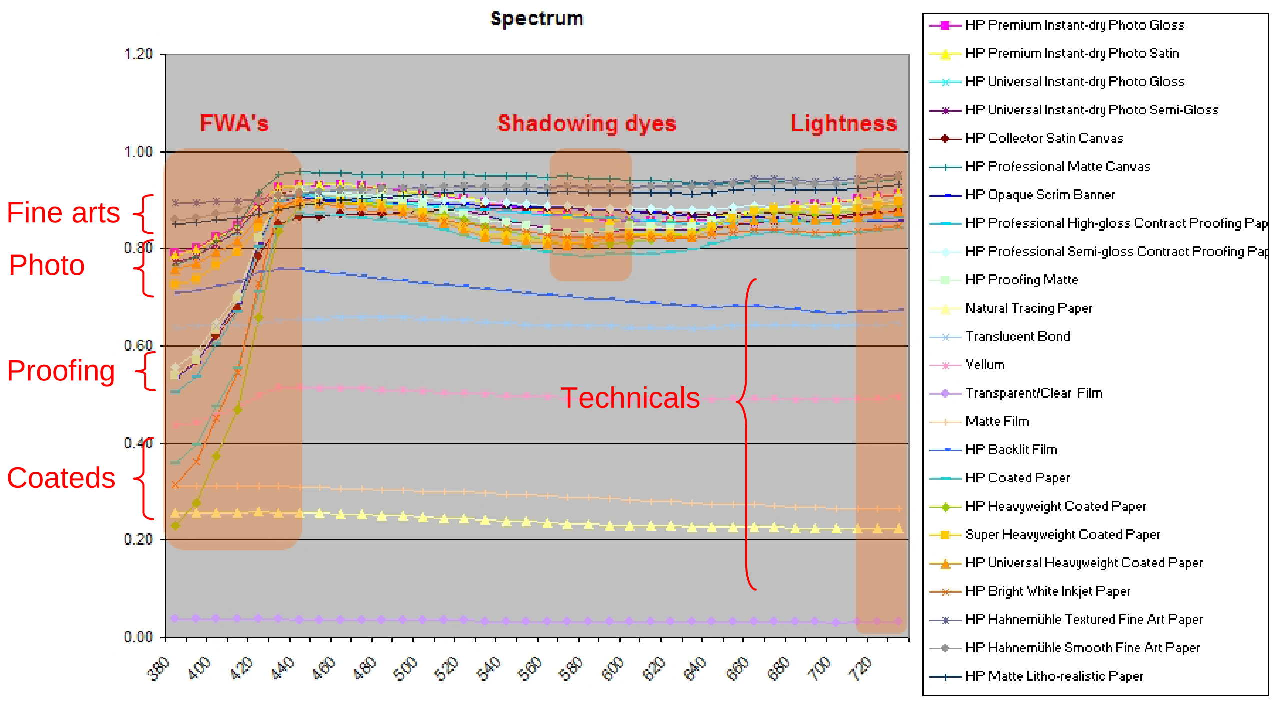

Figure 5-4 Paper spectrum measured with spectrolino

Moreover, it is possible to observe how papers from the same family have the same behavior making things easy for us.

5.3.2. Spectral measurements

The problem is that in the embedded spectrophotometer which is limited to the range 420 to 700nm looses the main part of this signal. This challenges the implementation of the Automatic Media Identification algorithm. In Figure 5-5 there are the measurements of the same medias but this time with the embedded sensor. It is important to point out how this signal has been degraded from the previous clear case.

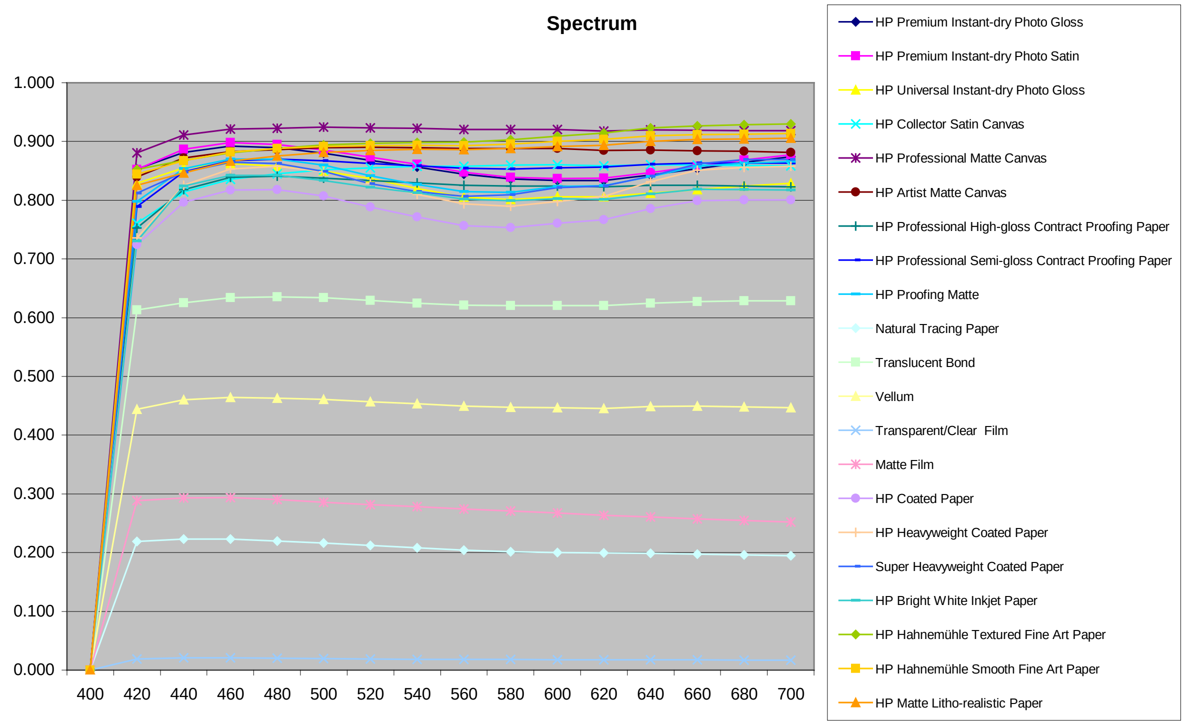

Figure 5-5 Paper spectrum measured with the embedded sensor

At this point there are some considerations to take into account to perform the analysis. Firstly we need to determine where the information is. As we saw in previous chapters, there is some noise in spectral measurements, so in order to reduce it, it seems reasonable to filter this spectrum and use only the wavelengths where there is more information. For example, if we look at the distribution of the points at 680 and at 700nm they are almost the same. It is more possible that any difference between them come from measurement noise that from a substrate difference. So to limit the power of measurement noise, we “filter” discard all the wavelengths where there is not enough information. In other words, we select the wavelengths where the signal to noise ratio is bigger.

In this case we have selected 460 related with the FWA, 580 to collect all the information from the shadowing dyes and 660 which is correlated with the lightness.

5.3.3. Identify technical substrates (660nm)

In order to reduce the complexity and as it was said before, we are going to identify the technical medias. To do it, we can analyze the 660nm point. Although in genera it is not recommended, there is enough signal to work with the absolute measurement.

In the next chart we have the sixteen measurements of each media represented and the name of each of these media.

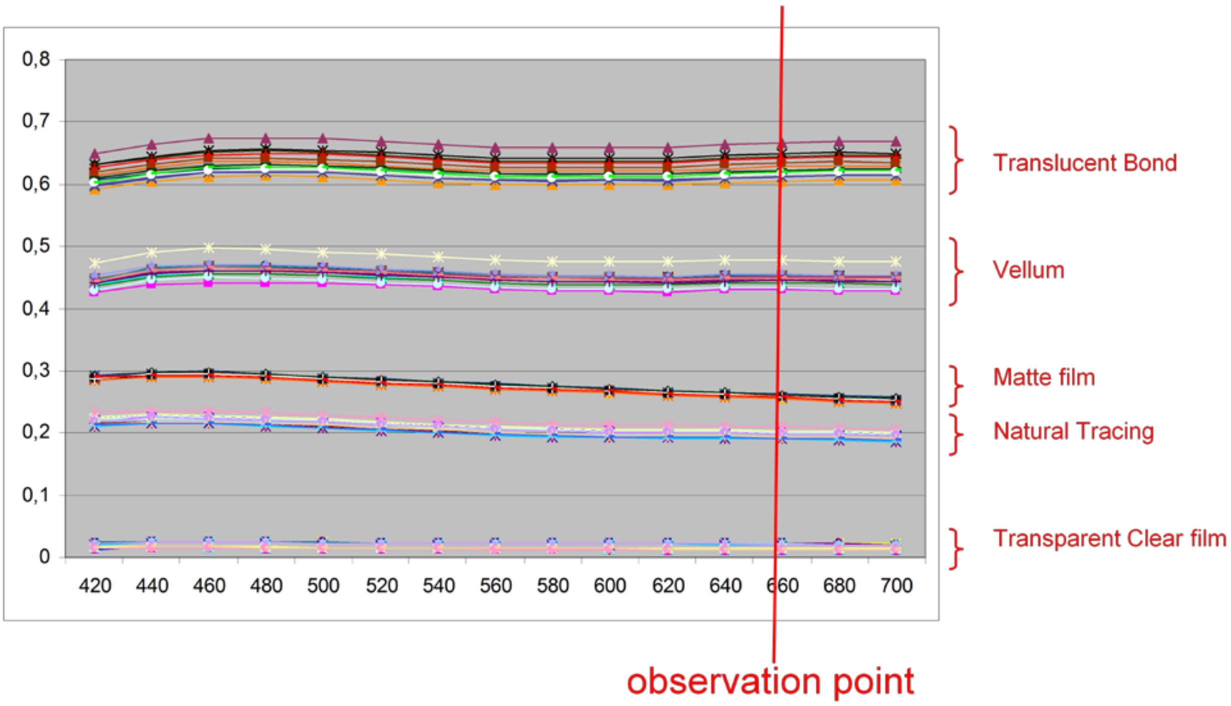

Figure 5-6 Technical medias spectrum repeatability

In this case it is more useful to use a representation of the 660 point for each substrate.

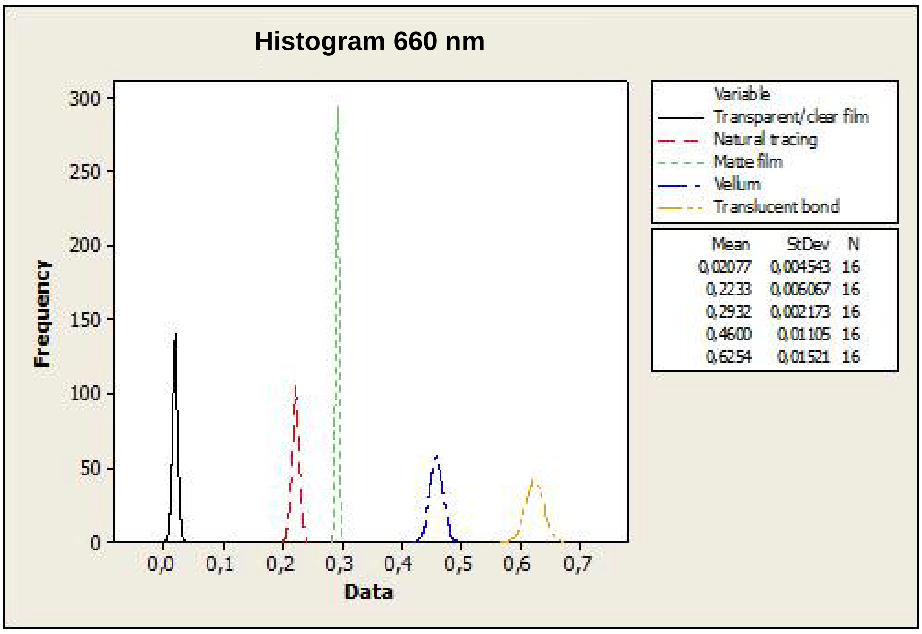

Figure 5-7 Histogram technical medias 660nm

To do the analysis of the thresholds and its success rate, we have used Minitab R14 software. The analysis performed is included in the next figures.

This tool builds a histogram for each data set based in the raw data that you provide. Then it calculates the average and the sigma parameters of a Gaussian bell that fits our data. Note that it is our task to check that this histogram follows a normal distribution, and therefore we can model it with a Gaussian shape.

In the case of the clear film media, its histogram is more like a bimodal. We have consciously modeled with a normal distribution because it is a worse case (greater sigma value) and we have enough signal to put the threshold value far enough.

In this threshold analysis, we have to provide the tool with the proposed thresholds (LSL[29] and USL[30]). The software will calculate the C_{pk} index both for the upper and for the lower side of the distribution. It is our task to calculate a threshold that is centered and provides the same fail rate for the two media that are distinguished by lowering the overall failure rate.

[29] Lower Side Limit
[30] Upper Side Limit

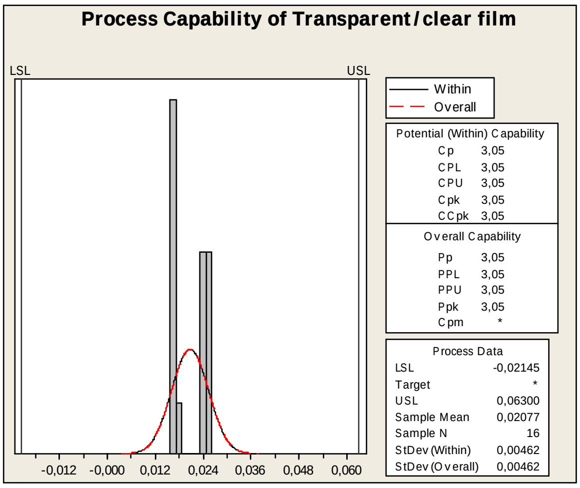

Figure 5-8 Clear film 660nm

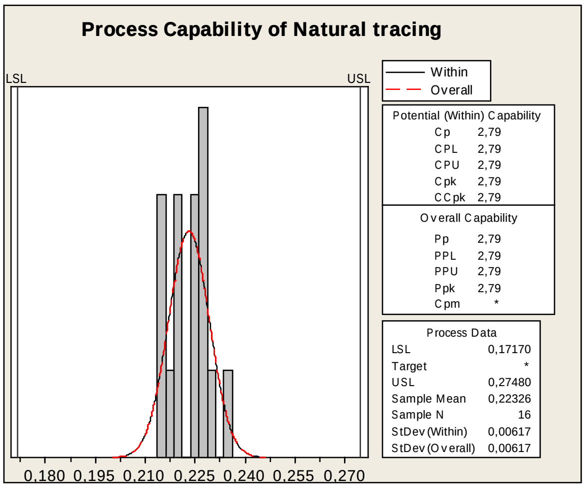

Figure 5-9 Natural tracing 660nm

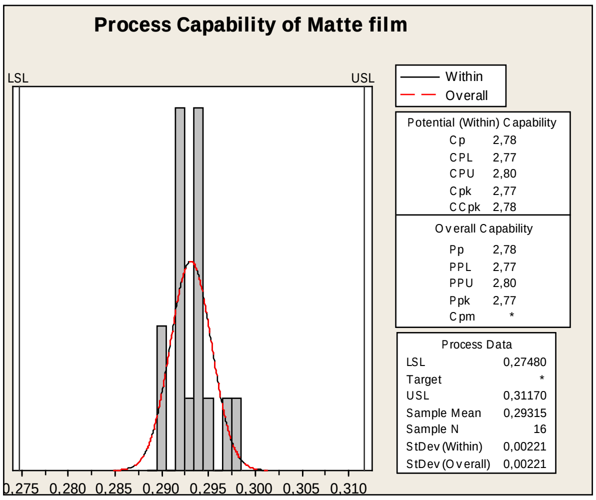

Figure 5-10 Matte film 660nm

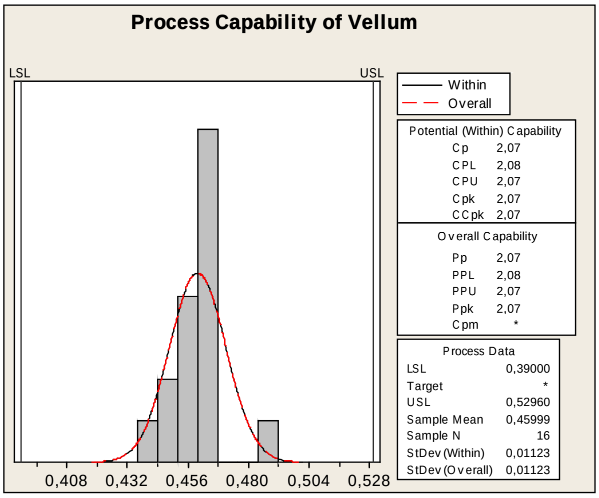

Figure 5-11 Vellum 660nm

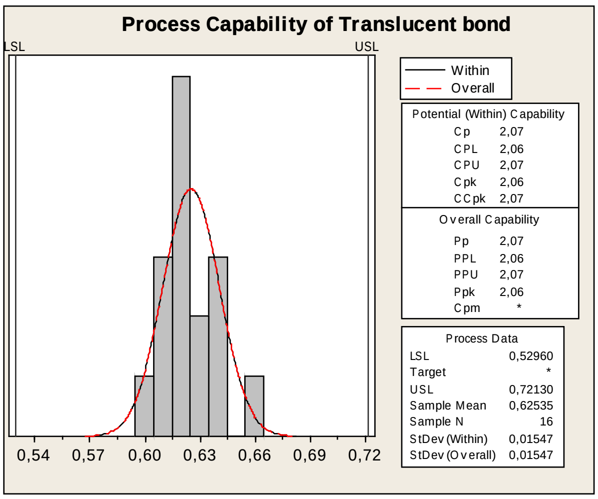

Figure 5-12 Translucent 660nm

So, the selected thresholds are tabulated bellow. Note that natural tracing and matte film have their capability limited because of they are sharing their USL and LSL thresholds value. This situation repeats again with Velum and Translucent papers.

Media type	LSL	USL
Clear film	0	0.063
Natural tracing	0.170	0.274
Matte film	0.274	0.312
Vellum	0.390	0.529
Translucent	0.529	0.721

Table 19 660nm tresholds

As a result the classification table for this method is the same than previous two methods but with a bigger success rate. Note that in this case the C_{pk} index is bigger than two for all of them and according to the learning's in section 5.1.1 C_{pk} methodology in page 99 that means that the success rate is 99.9999998%. In other words, these substrates would be misclassified less than one time per million, without any doubt more than enough for our application.

Identified Medias

Family 1:	Tech.	clear film
Family 2:	Tech.	natural tracing
Family 3:	Tech.	matte film
Family 4:	Tech.	vellum
Family 5:	Tech.	translucent bond
Family 6:	All	glossy HG / glossy SG / casablanca / plain / proofing matte / coated / HWC / sHWC / canvas satin / canvas artist / professional canvas / prrofing SG / HG proofing / mate litho / smooth FA / texture FA

Table 20 660nm Classification table

5.3.4. Ratio between 580-460nm

In this section we are going to study the signal that we are able to measure due to the FWA peak and the valley produced by the SD. It is interesting to note that technical media are not included in this study because they are supposed to be identified in a previous step and this will help us to reduce the complexity of the analysis.

Positive values mean no SD no FWA (the spectrum is increasing), values near to zero means small amount of FWA and no SD, finally a negative value means big amounts of both SD and FWA.

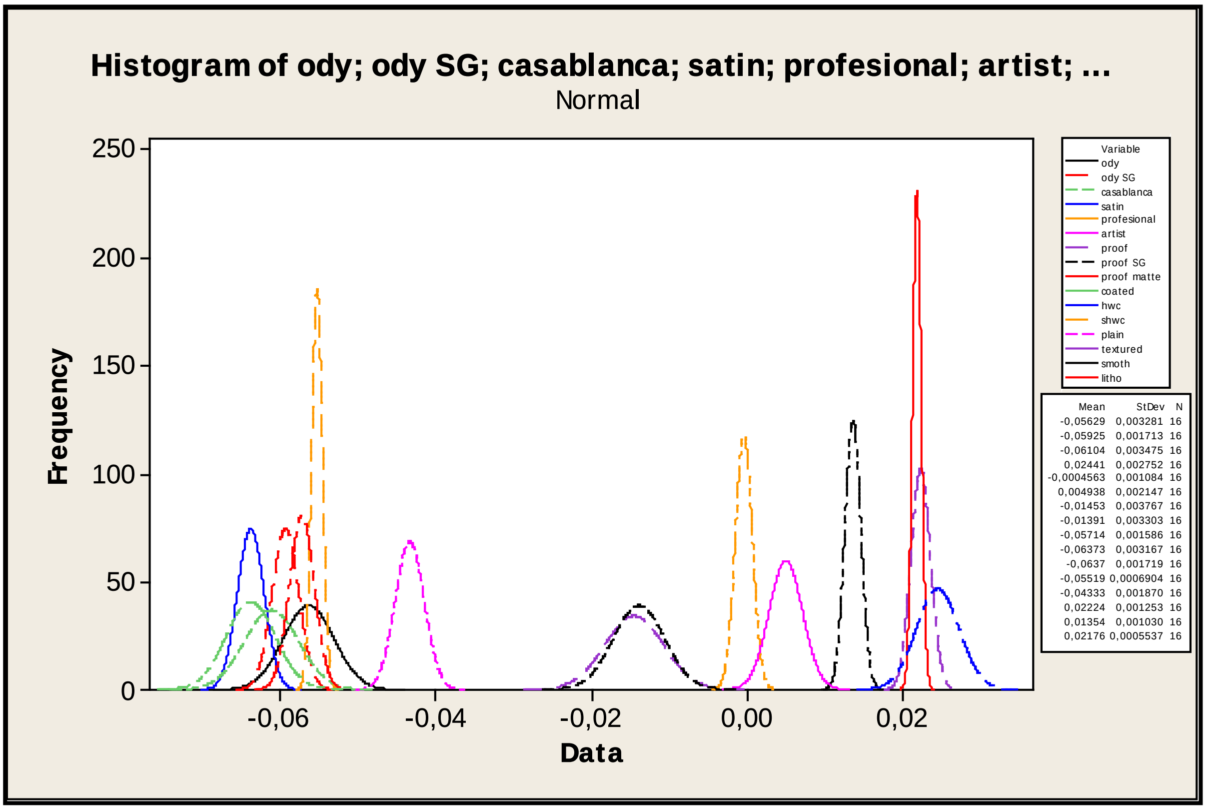

Figure 5-13 580-460 wavelength

We can easily see that we can put a threshold around -0.03 to divide them in two groups. While this may be seen as a bad metric (previous methods identify some substrates) this method is able to identify families which is much more useful. So, in the right side of the threshold we may have proofing, Fine Arts and Canvas substrates and in the left side we may have coated and photo substrates.

Using again the Minitab R14 software, we found the optimal threshold at -0.03526. It is important to note that to perform the threshold analysis we have to identify the worst case. As it was learnt in previous section, this is defined by the two Gaussian shapes which are closer (closest average value) and with a bigger variability (bigger standard deviation). In our case this happens with plain paper and proofing SG.

In this case the C_{pk} index is not as good as in the previous method. By the way, C_{pk} = 1.67 has a success rate of 99.9999% equivalent to a 5σ.

In the following figures you can see a detailed analysis. The threshold selected has been set at -0.03378. As we have explained we have selected plain paper and proofing HG as the worse case. These are the two Gaussian bells that are closer to the area that I found to set the threshold and are the ones that have a greater sigma value.

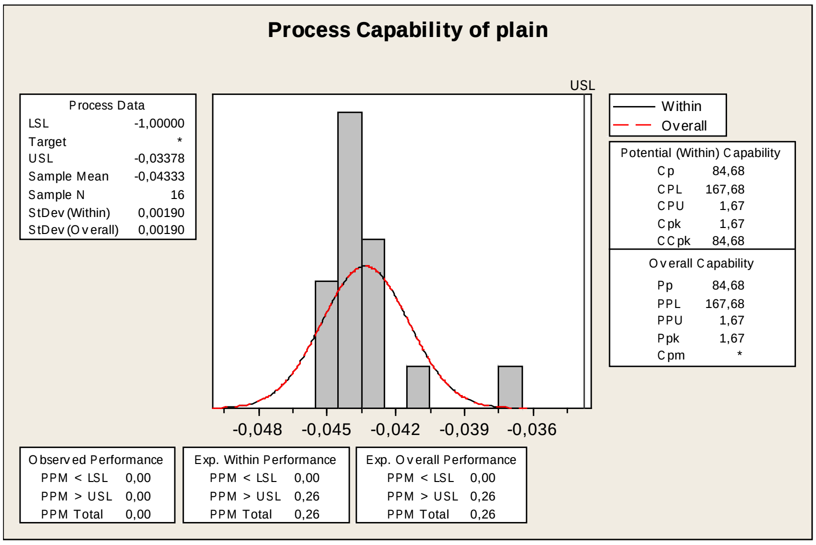

Figure 5-14 580-460 Plain threshold capability

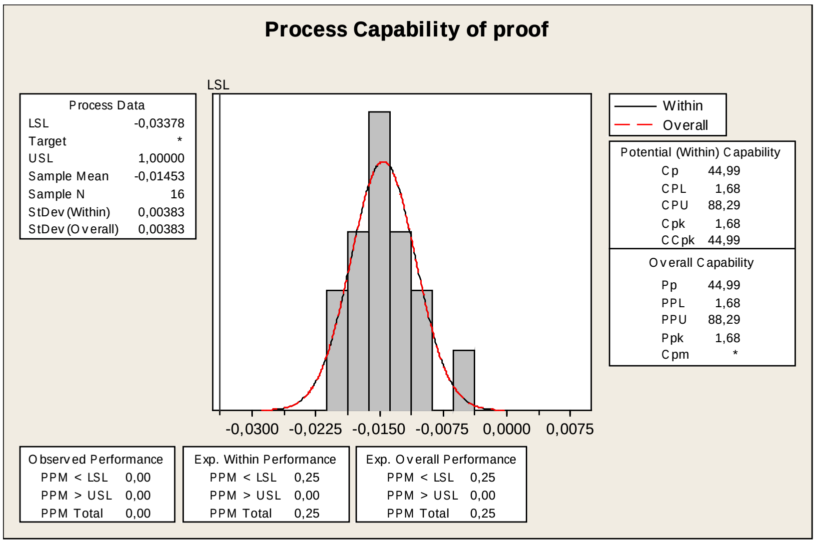

Figure 5-15 580-460 Proofing HG threshold capability

So finally the classification table for this method is:

Identified Medias

Family 1:	FA	litho / textured / smooth
	Canvas	satin / artis / professional
	Proof	proofing SG / proofing HG
Family 2:	Coated	plain / coated / HWC / sHWC / proofing matte
	Photo	glossy HG / glossy SG / casablanca

Table 21 580-460 Classification matrix

5.3.5. Ratio between 660-580nm

In this section, we are going to study the 660 and the 580nm wavelength. we have chosen these values for two reasons. The 660nm is a frequency at the edge of the visual spectrum, corresponding to red color, which has a more stable behavior across the HP media set. Due to the fact that the ideal blank media would have a plain spectrum (same response at all wavelengths) and the greater this response is, the bigger the lightness value is, we found the 660nm wavelength to be a good estimator of the lightness value with a really high correlation.

Then, when we compare 660 and 580nm wavelengths we are comparing the amount of shadowing dyes with the lightness value of the paper.

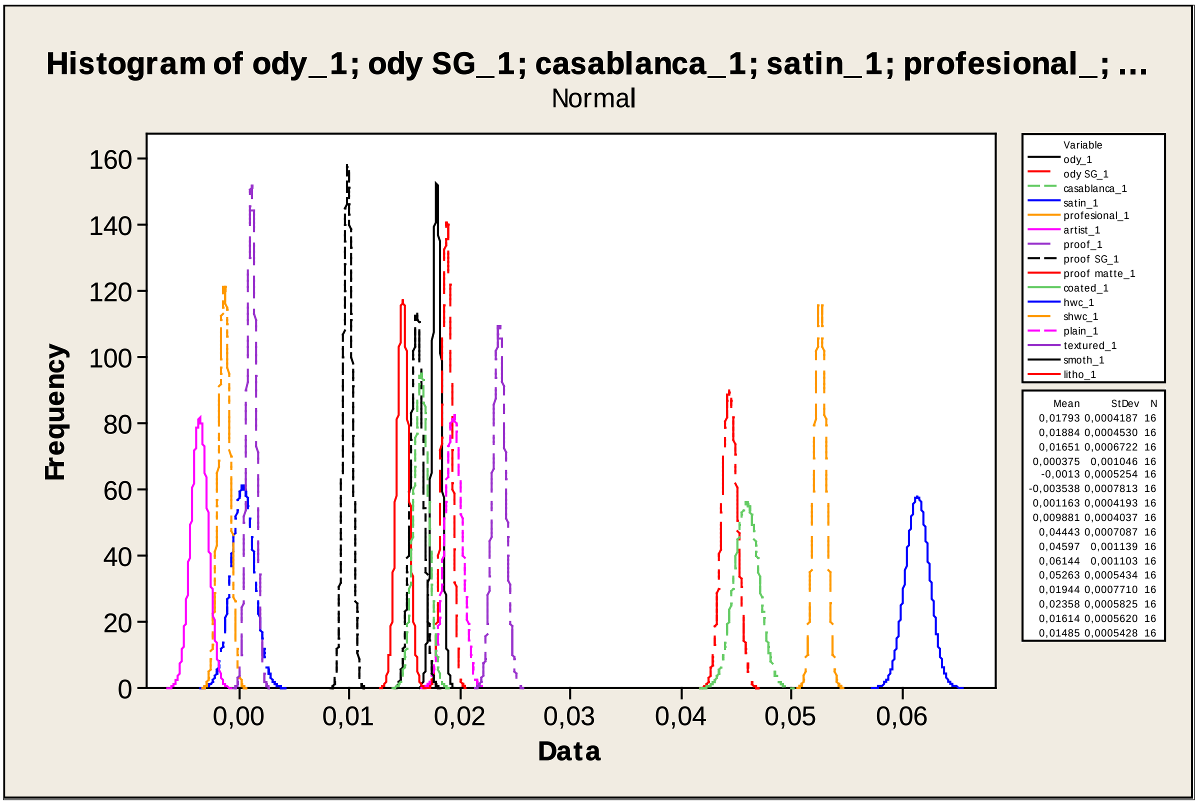

Figure 5-16 660-580 wavelength

By looking the graph, we can see that there are two clear areas to set a threshold around 0.006 and around 0.032. It also seems possible to set a couple more at 0.011 and 0.055. As this is not the final method, we have not calculated the capacity of these thresholds. Just to simplify, let assume that they are at enough distance to be identified with sufficient confidence.

In this case, the classification table would be as follow.

Identified Medias

Family 1:	HWC
Family 2:	proofing matte / coated / sHWC
Family 3:	textured / plain / glossy HG / glossy SG / smooth FA / litho / casablanca
Family 4:	proofing SG
Family 5:	proofing HG / canvas satin / canvas artist / professional canvas

Table 22 660-580 Classification table

Here the take away is that even it can identify completely a couple of substrates, the remaining are classified without following a clear pattern.

5.3.6. Ratio between 660-460nm

In this case we have selected the two wavelengths corresponding to lightness and the peak of the FWA. As before, we are going to look, in the next figure, for a place where to set a threshold.

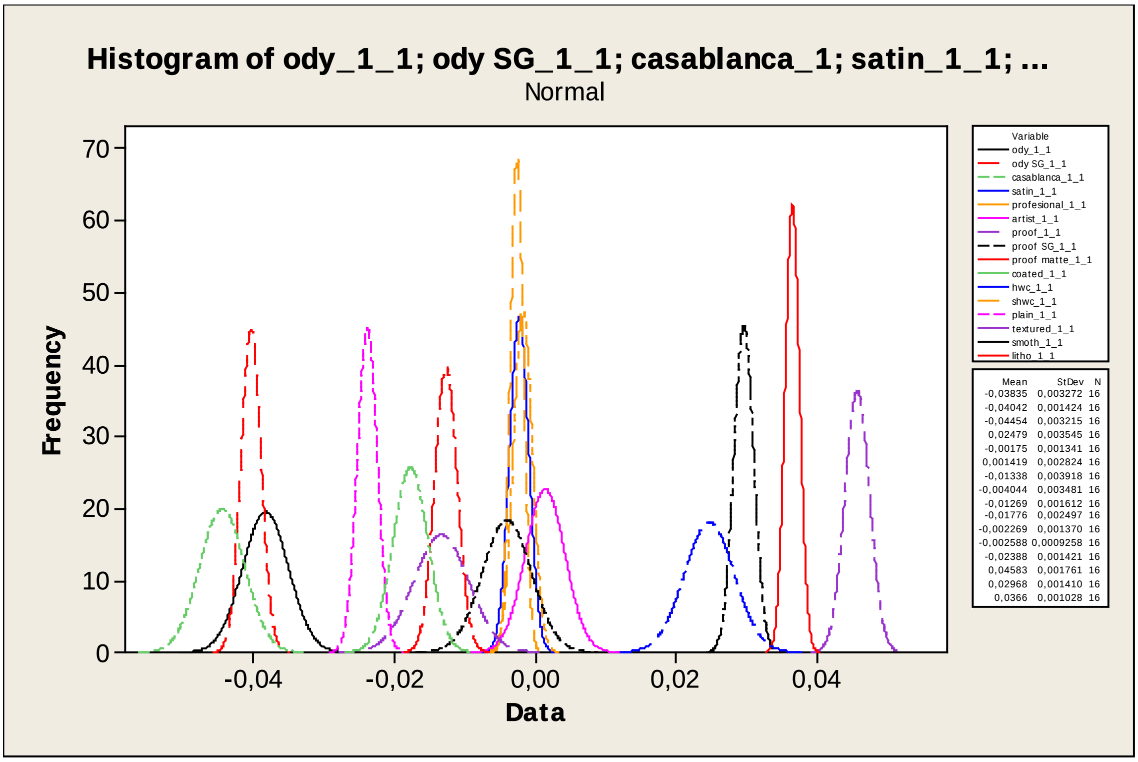

Figure 5-17 660-460 wavelength

In this case there is not any clear case. All papers are superimposed and there is not any possibility to do a classification. So, at this point we are not going to perform any threshold analysis. Although it seems not useful to use this data, we will see in the following sections how this helps to us.

5.4. GLOSSINESS ANALYSIS

In this section we are going to study what papers can be identified if we only use the embedded gloss meter data. You can take a look into the appendix in the section 7.3 to take a look at the raw data.

5.4.1. Diffuse vs Specular channel

Now, we are going to take a look at a few measures made with this sensor with both channels specular and diffuse in some of the different media types that we are going to study. These measures have been done with the green LED with several repetitions and at different sensor to paper distance.

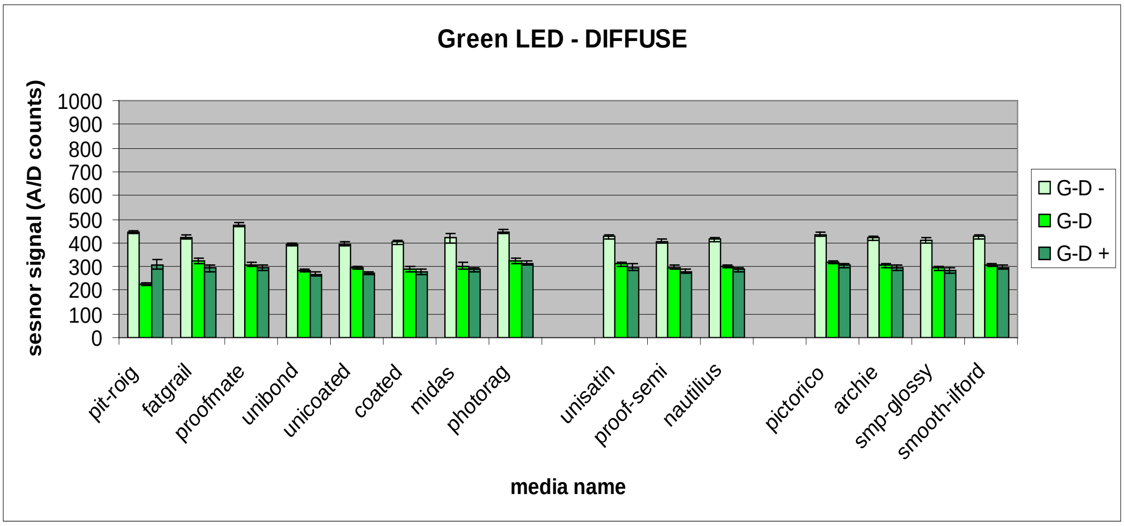

Figure 5-18 Gloss meter diffuse channel

In the Figure 5-18 we have the response of the diffuse channel. As we can see it seems that there is not any signal between papers to process. The only variations in the signal are related with the height of the sensor respect to the media. The closer to the media the bigger the signal is. That is easy to explain, if you are near the paper there is less light that is scattered and reaches the photo receptor getting the maximum signal.

Although it seems that the diffuse sensor is useless to our purposes, it has a relevant value to us. We want to use the diffuse channel to normalize the specular measurement that contains the information making it independent of the amount of light that emits the LED.

In the following Figure 5-19 we can see how the specular channel is sensitive to the different media types. More precisely it seems to be three groups, low signal, medium signal and high signal that correspond to non-gloss, semi-gloss and high gloss categories. It is important to understands that that we can not only use the absolute ADC value because there are other factors as the current of the led or the distance to the media that affects this absolute value while maintaining the proportionality. As these two effects distance and current affect the two channels of the sensor it is possible to normalize to extract the information.

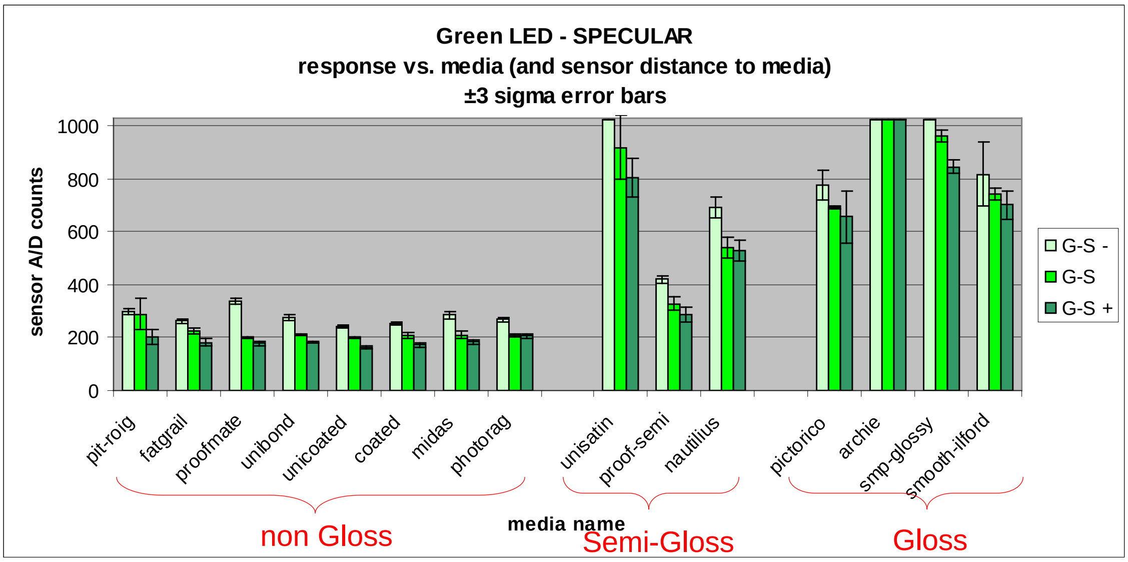

Figure 5-19 Gloss meter specular channel

$$P_{specular} = P_{led} * \left[\left(R(90^{\circ}) * G_{nominal} \right) + \left(R(90^{\circ}) * E_{specular} \right) \right] \quad (61)$$

$$P_{diffuse} = P_{led} * \left[\left(R(45^{\circ}) * G_{nominal} \right) + \left(R(45) * E_{diffuse} \right) \right] \quad (62)$$

Taking into account that $R(45^{o})$ is constant and assuming that the production line calibration has worked $Gnominal >> Especular$ and $E\ diffuse$.

$$Reflectance\ ratio = \frac{P_{specular}}{P_{diffuse}} = kR(90^{\circ}) \quad (63)$$

5.4.2. Data analysis

In theFigure 5-20, we can find the distribution of the ratio of each substrate. As you can check the distribution of each paper has been modelled using a Gaussian shape. So, the repeatability of the measurements is very good and the standard deviation is low enough. Based on this we can set different thresholds to identify media. By the way, it is important to see that we can identify different families but we will not be able to totally identify some substrates.

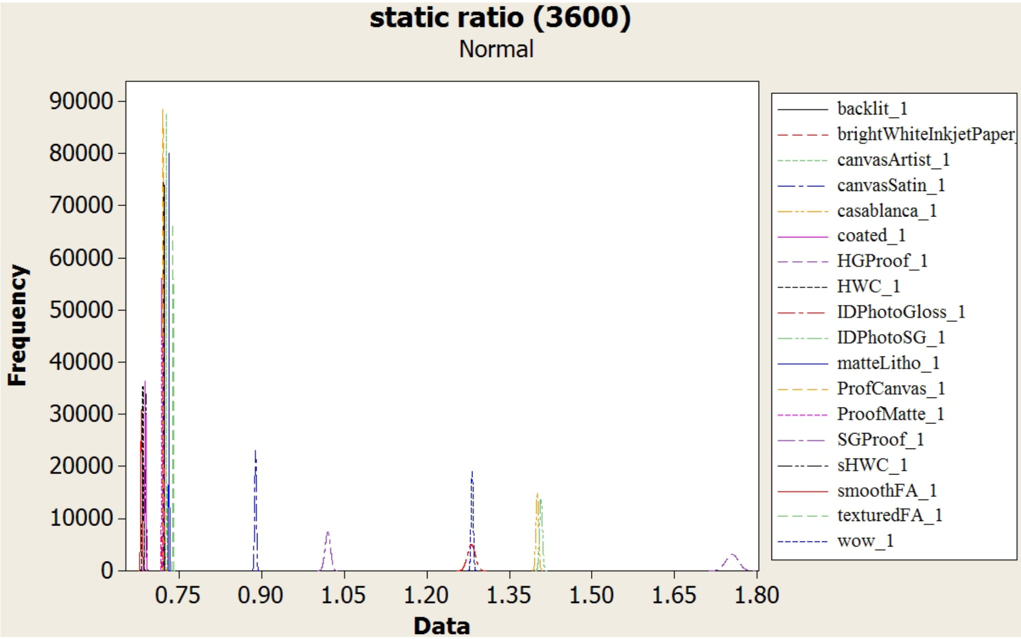

Figure 5-20 Glossiness ratio

At this point, we have not found the optimal thresholds to do this classification. This is due to this is not going to be the final method. Gloss meter will help us determining the difference between some papers that spectrophotometer is not able to distinguish. This will be seen in section 5.5 Combination of all methods.

5.4.3. Sensor capability

As a result here we include the classification table for this sensor.

Identified Medias

Family 1:	clear film
Family 2:	HG proofing
Family 3:	ID photo SG / casablanca
Family 4:	ID photo HG / WOW
Family 5:	SG proof
Family 6:	Canvas Satin
Family 7:	backlit / bright white / canvas artist / canvas professional / matte litho / proofing matte / textured
Family 8:	coated / HWC / sHWC / smooth FA

Table 23 Gloss meter classification table

5.5. COMBINATION OF ALL METHODS

5.5.1. Introduction

The idea of this section is to propose an analysis workflow that combines the previous techniques and allows us to identify more substrates than any other method by itself. To do it we am going to apply the previous method but in a cumulative way. That means applying the next method to the output of the previous method. This will help a lot due to the possibility to do more classifications as histograms will be easier every time that a classification will be done.

5.5.2. Analysis workflow

The proposed workflow has three stages: classify technical substrates, perform and spectral analysis and finally do the glossiness analysis. Each of these states would be explained in the following sections.

5.5.2.1. Classify technical substrates

As we saw in section 5.3.3 Identify technical substrates (660nm) on page 110 where the process has been widely covered, technical substrates can be easily identified by studying its reflection level to a 660nm lightsource.

At this point the classification table is:

Identified Medias

Family 1:	Tech.	clear film
Family 2:	Tech.	natural tracing
Family 3:	Tech.	matte film
Family 4:	Tech.	vellum
Family 5:	Tech.	translucent bond
Family 6:	All	glossy HG / glossy SG / casablanca / plain / proofing matte / coated / HWC / sHWC / canvas satin / canvas artist / professional canvas / prrofing SG / HG proofing / mate litho / smooth FA / texture FA

Table 24 Classification table stage 1.0

5.5.2.2. Spectral analysis

The spectral analysis workflow can be summarized in the following flowchart. In it you can see that there are three analysis stating by 580-460, then apply 660-580 to the output and finally 660-460.

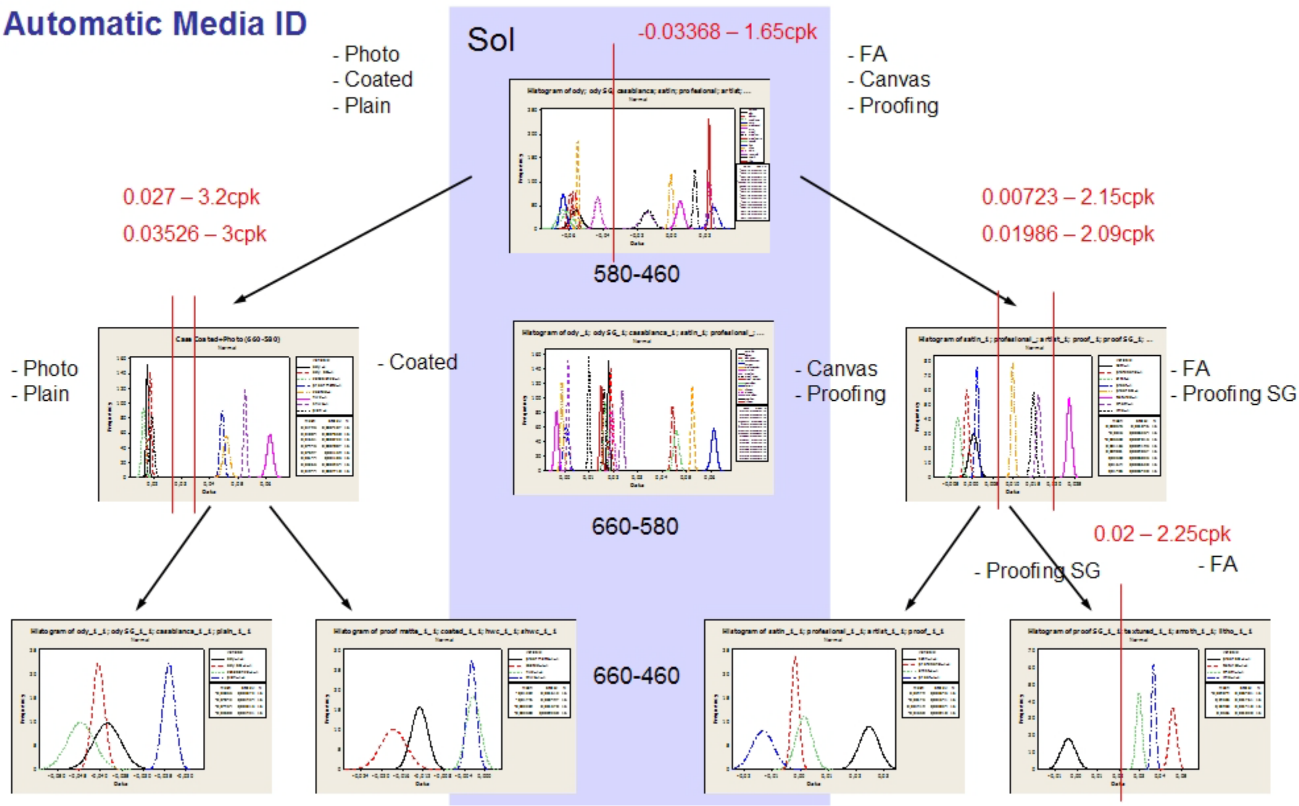

Figure 5-21 Automatic media ID proposed analysis flow

580-460 (Classify photo, coated, plain / FA, canvas , proofing)

This method has been also fully described in section 5.3.4 580-460 on page 113. It is important to note that technical substrates have been removed to do this analysis. What we learnt was that papers are classified in two categories photo, coated and plain and in the other side fine arts, canvas and proofing. Now the accumulated classification table is as follows.

Identified Medias

Family 1:	Tech.	clear film
Family 2:	Tech.	natural tracing
Family 3:	Tech.	matte film
Family 4:	Tech.	vellum
Family 5:	Tech.	translucent bond
Family 6:	FA	litho / textured / smooth
	Canvas	satin / artis / professional
	Proof	proofing SG / proofing HG
Family 7:	Coated	plain / coated / HWC / sHWC / proofing matte
	Photo	glossy HG / glossy SG / casablanca

Table 25 Classification table stage 2.1

660-580 (Classify photo, plain / coated / canvas, proofing / proofing, FA)

This spectral metric was introduced in section 5.3.5 660-580 on page 116. The difference is that now, we are going to apply this analysis to family 6 and family 7 (look at Table 25 Classification table stage 2.1) obtained in the previous stage.

This is very important because instead of make the analysis over the Figure 5-16 660-580 wavelength with sixteen substrates we do it on two sets of eight and nine substrates respectively, reducing the complexity and allowing setting thresholds in areas where they were not clear. It is important to see how the region between 0.01 and 0.025 has been simplified.

In the next figure we can foresee the possibility to set a threshold in the neighbourhood of 0.03. The most important here is to note that the left area of the chart is composed mainly by photo papers while in the right area there are the coated materials.

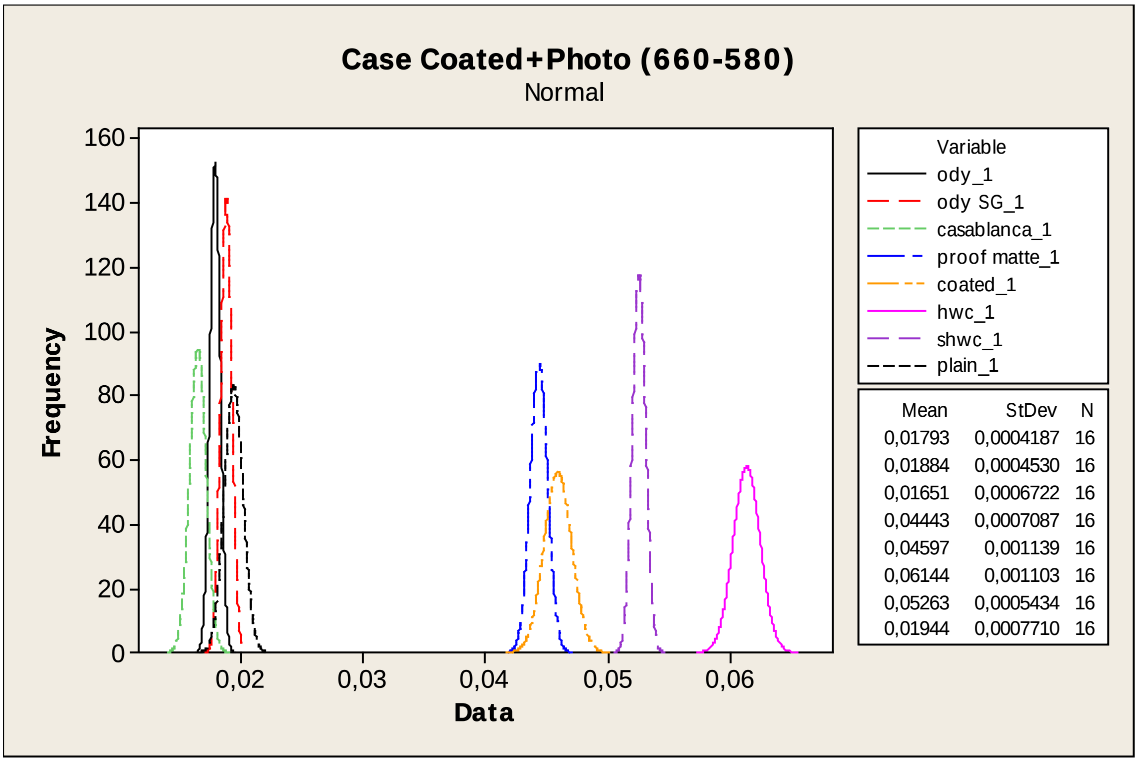

Figure 5-22 Family_7 660-580

In this case it there was so much space that we selected two thresholds. One for the left area limited by plain and one for the right that could be limited by proofing matte or coated paper. So we found the threshold for both substrates and selected the more restrictive.

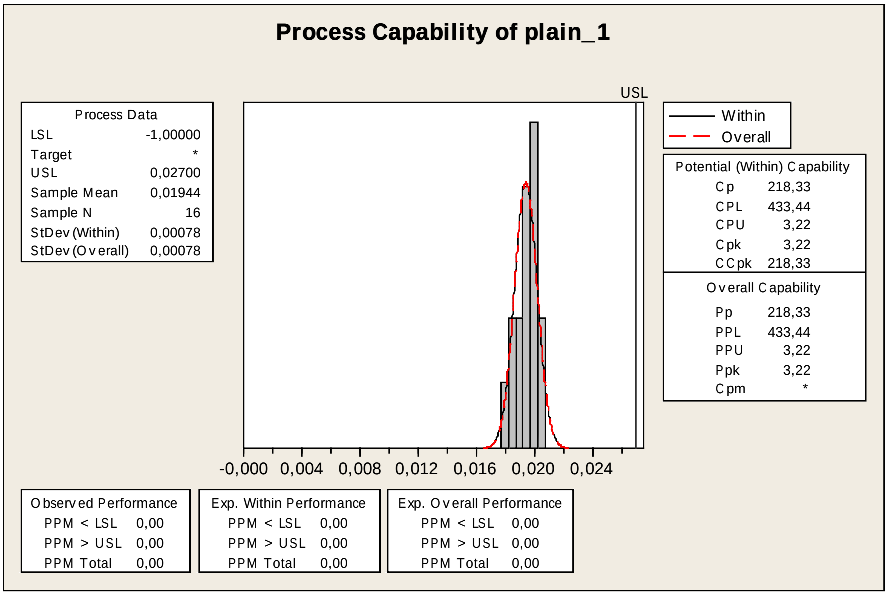

Figure 5-23 Plain 660-580 threshold capability

In this case the threshold for plain was 0.027 with a C_{pk} index of 3.22.

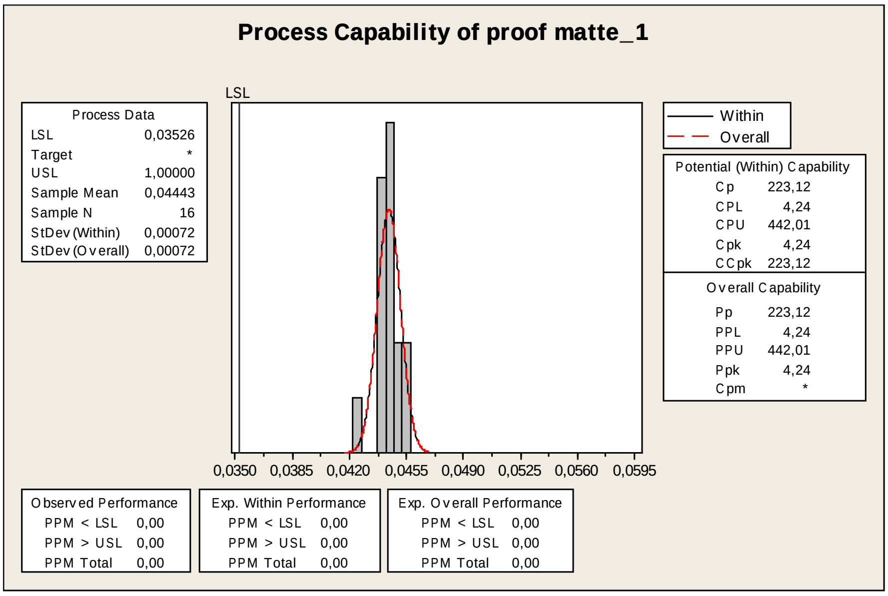

Figure 5-24 Proofing matte 660-580 threshold capability

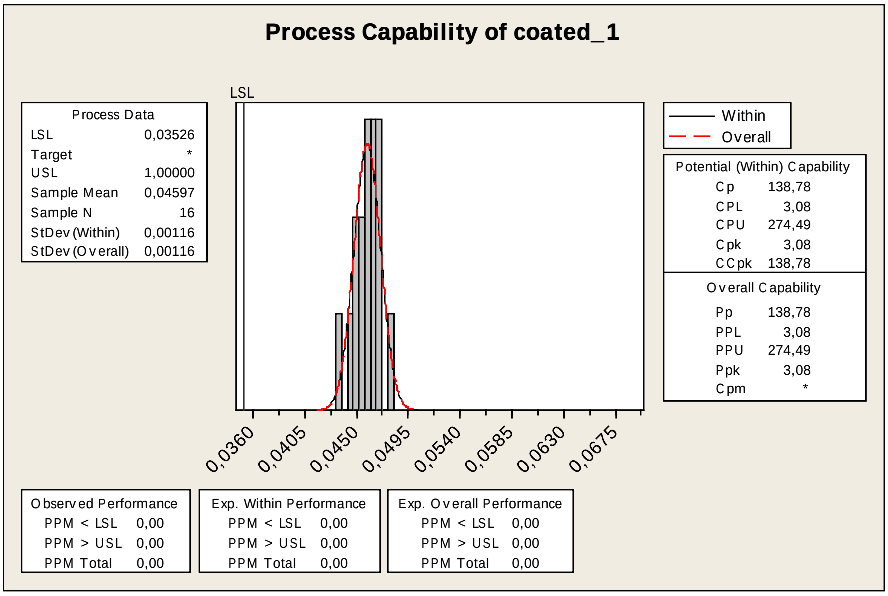

Figure 5-25 Coated 660-580 threshold capability

On the other side, the optimum threshold is 0.03526 and the worst case substrate was coated that limited the capability to 3.06 which is compliant with the 6σ methodology.

If we continue with the 660-580 analysis for family 6 we can check that this time substrates are also ordered. On the -0.005, 0.005 range there are the canvas family while values greater than 0.005 are fine arts materials. Proofing papers are distributed, but we should not worry about that at this stage.

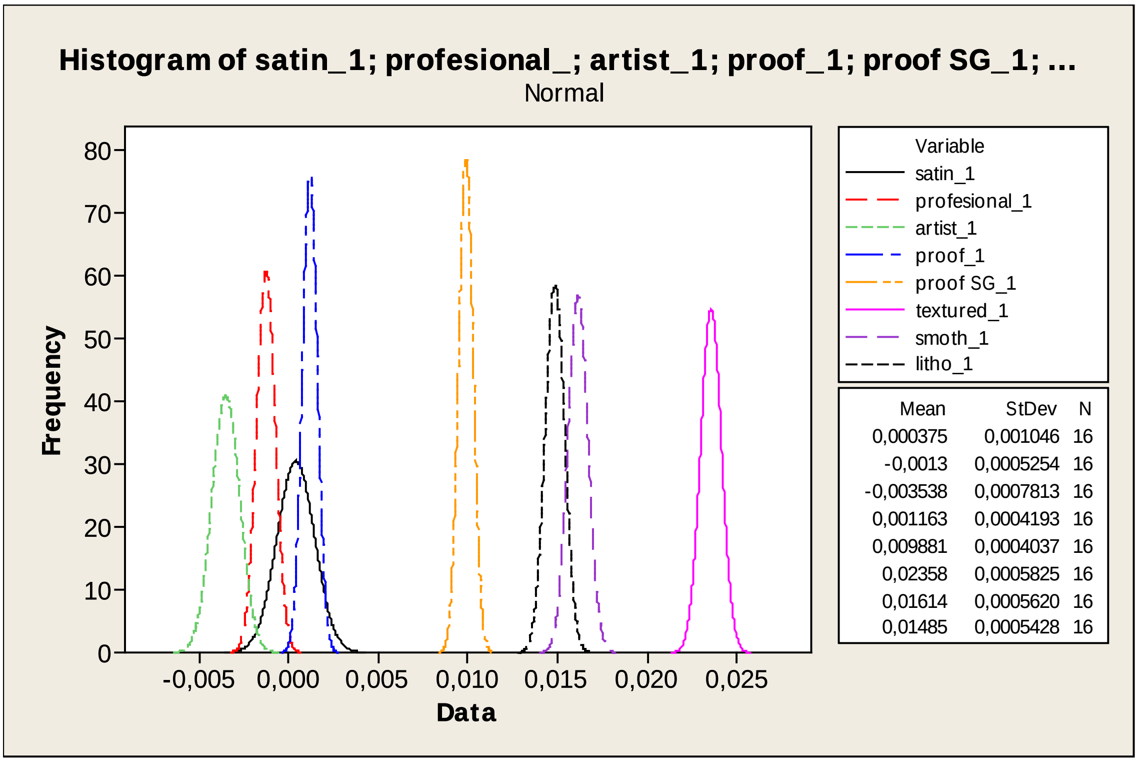

Figure 5-26 Family_6 660-580

This time we are going to place two thresholds, one in the 0.005 neighbourhood and the second near the 0.02. That means that there will be two capability studies.

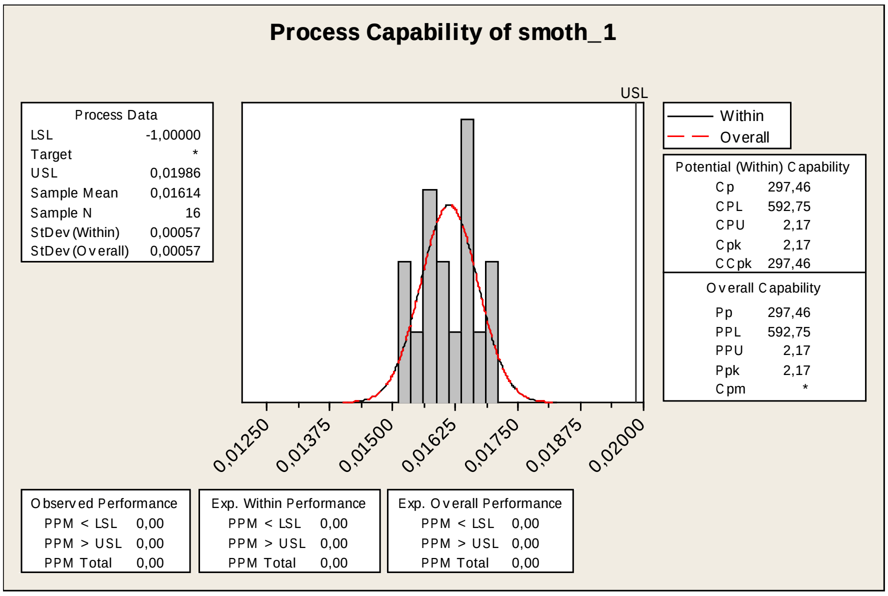

Figure 5-27 Smooth 660-580 threshold capability

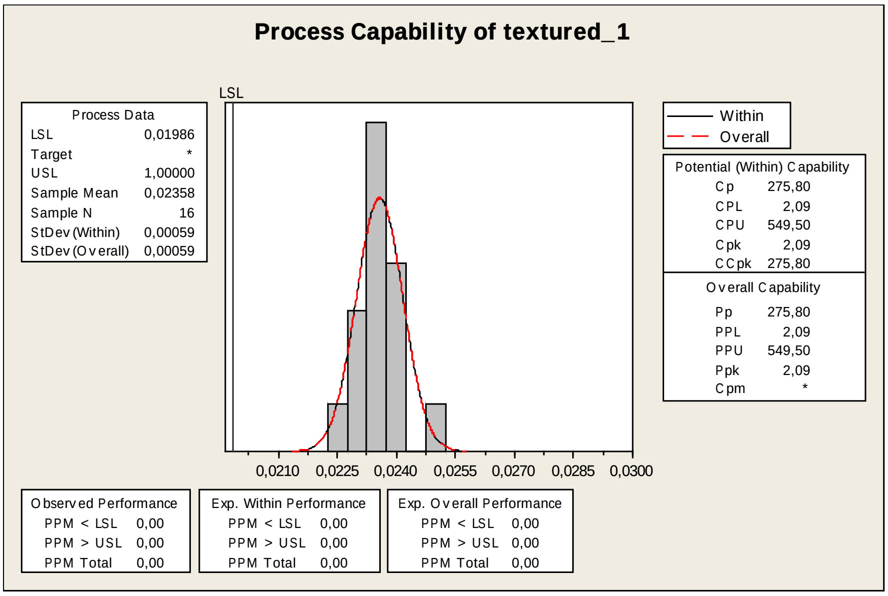

Figure 5-28 Textured 660-580 threshold capability

This threshold, at 0.01986, helps us to identify the HP textured fine art paper. So, it is not necessary to identify paper families but adds functionality to the system.

Finally the other threshold is set at 0.00723 and distinguishes both families canvas and fine arts with a capability of 2.15 which has a lot of margin.

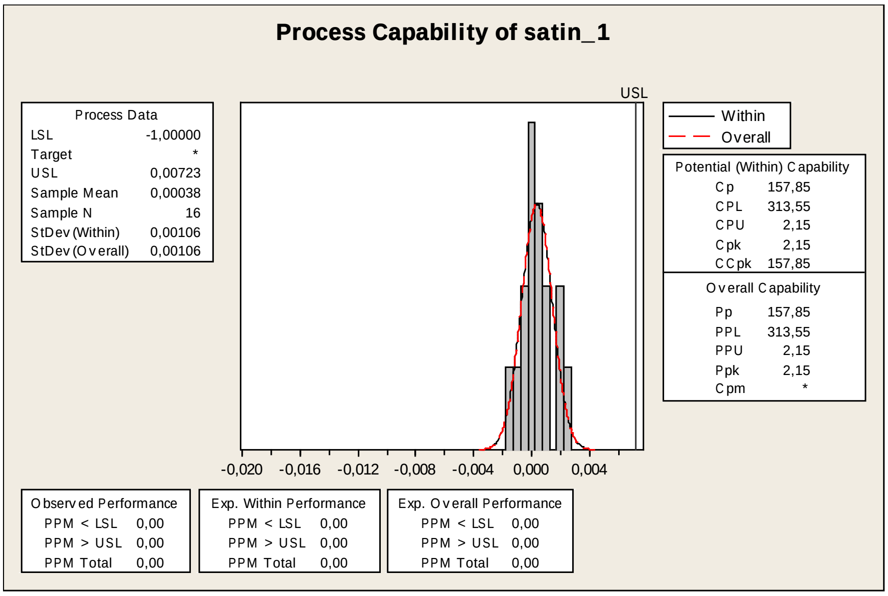

Figure 5-29 Canvas satin 660-580 threshold capability

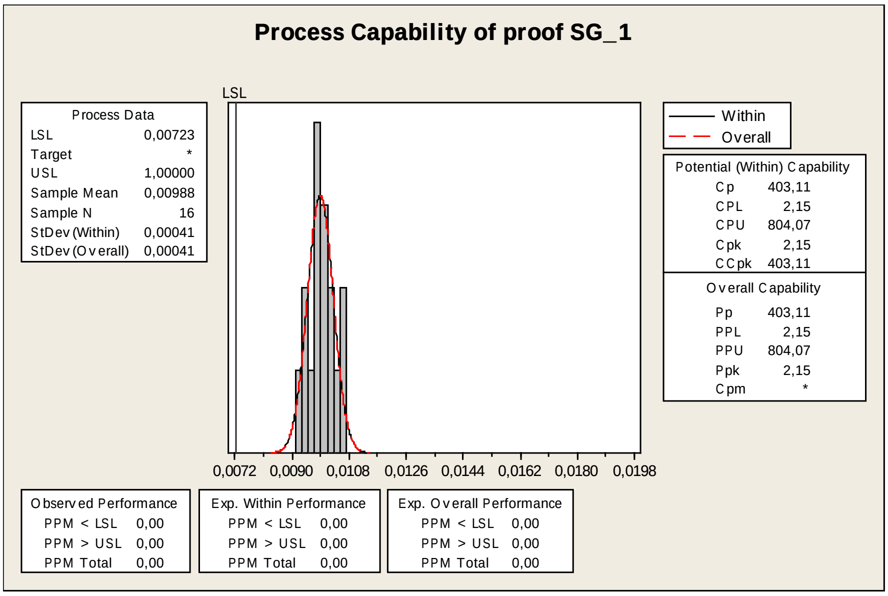

Figure 5-30 Proofing SG t660-580 threshold capability

If we incorporate all this new knowledge to the system, the new classification table at stage 2.2 is as follows. Although there are some papers misclassified, marked in bold letters, there is a clear tendency to have them ordered by families. In the next spectral analysis we solve some of them and finally using the gloss meter data we will have the final classification table.

Identified Medias

Family 1:	Tech.	clear film
Family 2:	Tech.	natural tracing
Family 3:	Tech.	matte film
Family 4:	Tech.	vellum
Family 5:	Tech.	translucent bond
Family 6:	FA	litho / smooth / **proofing SG**
Family 7:	FA	textured
Family 8:	Canvas	satin / artis / professional / **proofing HG**
Family 9:	Coated	coated / HWC / sHWC / proofing matte
Family 10:	Photo	glossy HG / glossy SG / casablanca / **plain**

Table 26 Classification table stage 2.2

660-460 (Classify photo, plain / coated / canvas, proofing / proofing, FA)

Finally with this analysis we can identify proofing semi gloss and isolate the fine arts family. But not only this, this gives us the possibility to make a good hypothesis on the rest of the substrates. we decided not to include it because the capability index was much lower than in the rest of the analysis increasing the probability of error.

As in the previous section, we are going to do this analysis on families 10, 9, 8 and 6-7.

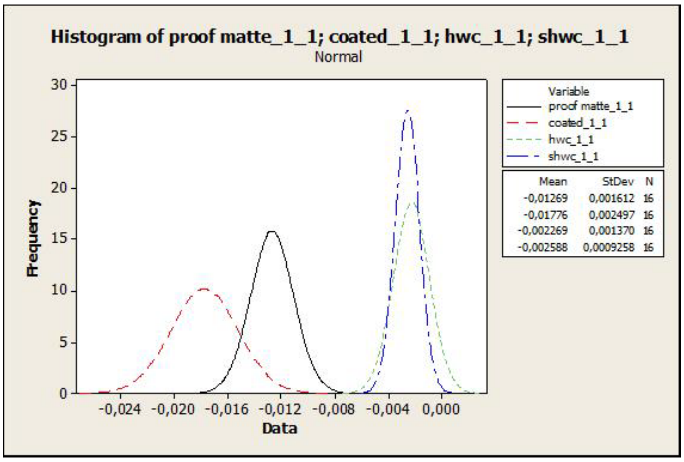

Figure 5-31 Coated family

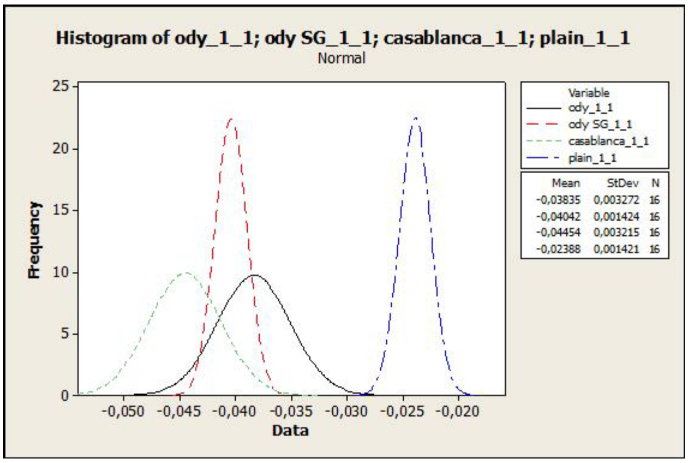

Figure 5-32 Photo family

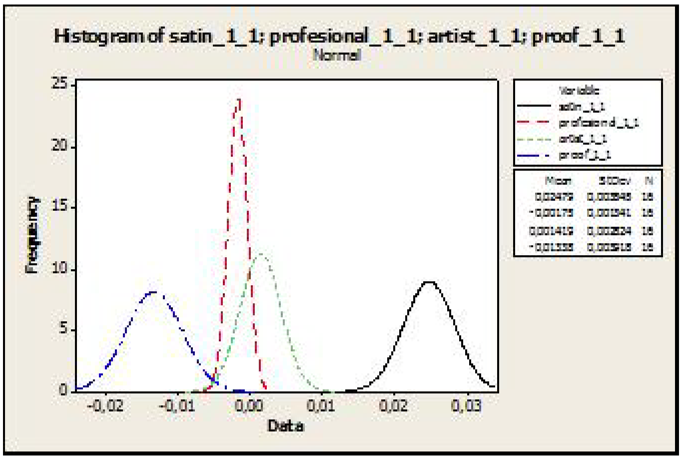

Figure 5-33 Canvas family

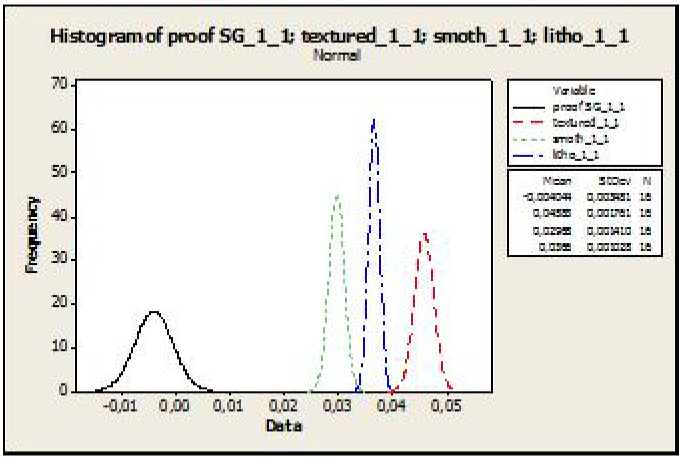

Figure 5-34 Fine arts family

Here we can see how there is only one clear case. It can be seen in Figure 5-34 Fine arts family. In the next page you may find the threshold analysis that allows to fully identifying proofing SG paper and that isolates all fine arts substrates in only one family.

As it has been said you can check how a good estimation can be done by putting thresholds to the fine arts papers and also to the canvas family.

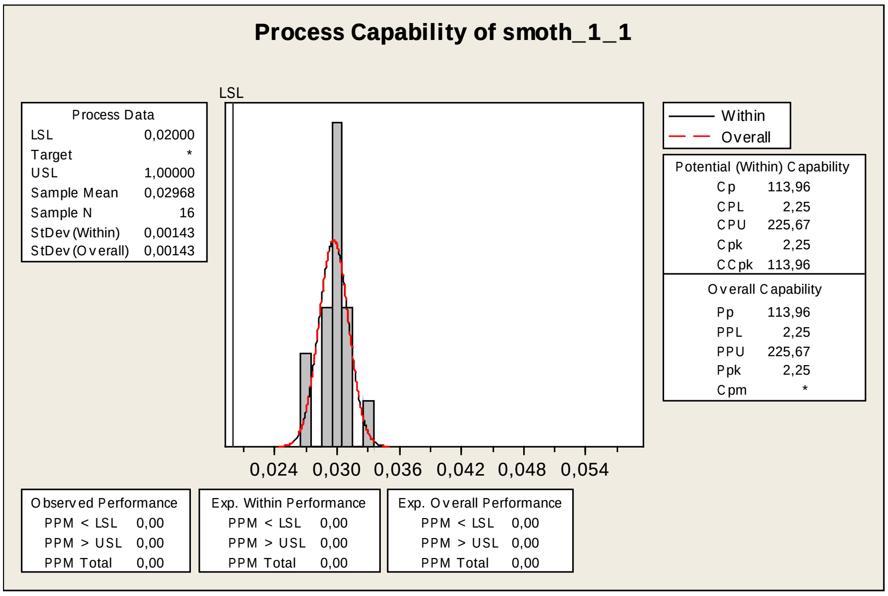

Figure 5-35 Smooth 660-460 threshold analysis

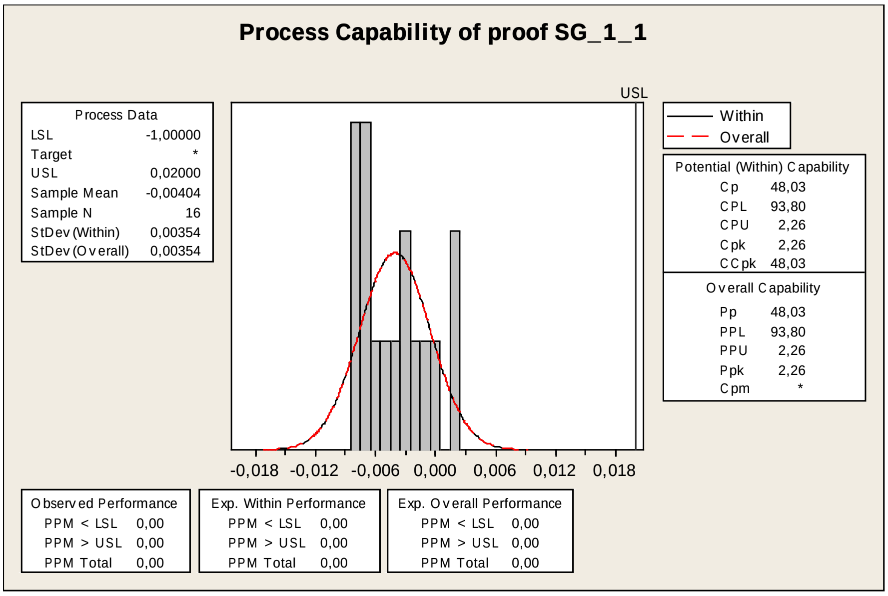

Figure 5-36 Proofing SG 660-460 threshold analysis

In this last case the selected threshold has been 0.02 and the obtained capacity index has been 2.25.

Finally using this new information, the classification table is as follows.

Identified Medias

Family 1:	Tech.	clear film
Family 2:	Tech.	natural tracing
Family 3:	Tech.	matte film
Family 4:	Tech.	vellum
Family 5:	Tech.	translucent bond
Family 6:	FA	litho / smooth
Family 7:	FA	textured
Family 8:	Proof	proofing SG
Family 9:	Canvas	satin / artis / professional / **proofing HG**
Family 10:	Coated	coated / HWC / sHWC / proofing matte
Family 11:	Photo	glossy HG / glossy SG / casablanca / **plain**

Table 27 Classification table stage 2.3

You can note that there are two misclassified papers that stills misclassified (marked in bold letters). Although this is not desirable, we can note how much different this papers are.

5.5.2.3. Glossiness analysis

Finally using the gloss meter data as defined in section 5.4 glossiness analysis but to the different families separately, we see that we can identify proofing HG, canvas satin, plain, smooth FA, proofing matte and photo HG.

The final classification table can be found in the next section 5.5.3 Method capability.

5.5.3. Method capability and conclusions

Finally after all these complex analysis, we get the results. With these sensors and methods, we are able to indentify 17 families, most of them with only one member. That means that most of substrates can be identified. We can see that papers that cannot be totally indentified share the same coating material as it was predicted in the early stages of the project.

It is important to note that there are some papers that even have been identified by themselves, glossy SG and glossy HG, they will finally use the same printer configuration to print images. On the other side, there are papers that even been classified in the same family would require of different print setting in order to print.

Identified Medias

Family 1:	Tech.	clear film
Family 2:	Tech.	natural tracing
Family 3:	Tech.	matte film
Family 4:	Tech.	vellum
Family 5:	Tech.	translucent bond
Family 6:	FA	litho
Family 7:	FA	smooth
Family 8:	FA	textured
Family 9:	Proof	proofing SG
Family 10:	Proof	proofing HG
Family 11:	Proof	proofing matte
Family 12:	Canvas	artist / professional
Family 13:	Canvas	satin
Family 14:	Coated	coated / HWC / sHWC
Family 15:	Plain	plain
Family 16:	Photo	glossy SG / casablanca
Family 17:	Photo	glossy HG

Table 28 Final list of identified medias

The most important is that based on the identified family we can reorder them by paper families. That very important and an important help to the customer as it will simplify the papers menu (actually composed by a two levels menu) with only one level reducing customers errors during the media load process.

6. CONCLUSIONS AND NEXT STEPS

6.1. SUMMARY

After a long journey of three years finally I am glad to conclude that the objectives of this project have been achieved. It has been a lot of time, not fully dedicated to the project, but always keeping the objective in mind.

To complete the first objective, namely, the design of the experiment and data collection, two measurement devices and two embedded sensors have been characterized. Automated tests have been defined to characterize the 23 different substrates that compose the HP media family of products. Huge amounts of data have been collected, ordered and pre-processed. I needed to program in the TCL language a few scripts to calibrate sensors and make measurements, python scripts to pre-process data and generate a database and use Matlab to do some analysis for that characterization.

In order to complete the second objective, namely, the investigation of the physical paper substrates properties, I did an observation task to identify differences and patterns between families of papers. I have done a deep study on paper characteristics and manufacturing processes. I have defined many different metrics to analyze all these data. All the proposed techniques have been based on physical characteristics of each media family to generalize the result and allow third party media to be also identified. Spectral data has become the difference with previous techniques and provided the capability to do this classification with this confidence in the result.

Last but not least, to achieve the third objective, which consisted of the definition of a set of rules to identify the different media, I have proposed an analysis workflow that combines different techniques in a smart way to get the expected classification results. To do it I have used Minitab R14 software and learnt a lot on processes improvement metrics.

By doing this project I have learnt a lot of new things in many different disciplines and not only in the telecommunications field. This has helped me to grow as an engineer in the broadest sense of the word.

But trying to keep the focus, the conclusion of this project is that it is feasible to identify different print substrates by analyzing their surface with a spectrophotometer and a gloss meter. It is also important to keep in mind the limitations of the algorithm which is that papers with the same coating material on its surface will be considered as the same paper. That means that if we would like to identify all possible substrates, we would need to add an extra sensor to the system to measure the paper thickness.

6.2. PATH FORWARD

Nowadays HP produces two different series of large format printers, the DesignJet T series meant for CAD users and the DesignJet Z series meant for the signage, photographic and fine arts market. The T series does not include a spectrophotometer so it does not have the ability of profile itself. Both the Z and the T series use a reduced version of the gloss meter that eliminated the specular channel sensor in a cost reduction.

That means that none of them have the two sensors that I have studied. The whole project has been done on a prototype based on a Z series printer plus a gloss meter with a specular channel and with a special firmware version to manage this sensor. So, the implementation of the project is not feasible without these changes.

While introducing the specular sensor on a Z series would have a not significant impact, cost below 0.5$, introduce the spectrophotometer in a T series would not be feasible from a financial point of view, cost increase up to 80$.

My proposal to overcome this situation is to design the architecture of a new low cost sensor based on the gloss meter. It would need to change the orange LED, not used in large format printers, by a UV LED. It would also need of an extra photodiode sensor to calibrate the power of each LED and a UV filter for the specular and diffuse channel. This would increase the cost of the gloss meter less than 1$ which is much cheaper than the spectrophotometer and can even be used in small format HP printers where cost is critical.

7. APPENDIX

7.1. HP IMAGING AND COLOR SYMPOSIUM (HPICS) PRESENTED PAPER

Automatic Media Recognition

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IPG

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Abstract

Every medium has unique physical properties that react with each type of ink in a specific way and under various illuminants provoke different perceptions to humans. There are also many printing pipeline parameters that have to be designed to optimize the image quality and throughput. Due to the endless number of combinations, every time a new printing pipeline is designed, a limited set of media is chosen and the various printing pipeline settings are fixed for each type of medium. Then, if the user loads one of these medium (normally paper based in most HP applications) and tells so to the printer controller, the predefined settings will be used and a correct Image Quality (IQ) will be obtained. However, wrong or bad IQ is obtained many times when user doesn't know how to select the right paper or wants to utilize a paper that doesn't have predefined printing settings. Within HP we have tried to know automatically the loaded paper in the past and several implementations have been put into the market. However, due to the type of detection done, the usefulness has been very limited. We describe how using the combination of a real spectrophotometer integrated inside the printer (SOL in HP Z-series DesignJets) and a line scan sensor (all these sensors are currently integrated in HP LFP printers), we can have enough information to automatically detect the loaded media in a printer using its color, IQ and surface physical properties and optimize then automatically the printed image quality. Being HP the only mass-market printer manufacturer with a printer-embedded spectrophotometer technology puts us in an advantage position over the competition to improve the usability of our printers and optimize automatically the image quality and color that our customers obtain under any circumstance, using any paper they want.

Background and Problem Statement

Most printing pipeline settings are designed depending on the printing media. There are infinite media with various fundamental properties that affect to the printing image quality and to the human perception of it: thickness, stiffness, glossiness, ink-media interaction, white point, etc. There are also many printing pipeline parameters that have to be decided to optimize the image quality and throughput: rendering resolution, color map, ICC color profile, ink limits, printing resolution, PPS, number of printing passes, etc.

Because we cannot design for all the available media (normally paper based in our applications), every time a new printing pipeline is designed, a limited set of papers is chosen and the various printing pipeline settings are fixed for each type of paper. Then, when a user loads one of these papers and tells so to the printer controller, the predefined settings are used and a correct IQ is obtained. However, 2 main problems appear many times: 1. What happens if the user makes a mistake when selecting the loaded paper? 2. What happens when the user wants to utilize a paper that doesn't have predefined printing settings?

The answer is always the same "wrong image quality". And many times it means "bad image quality and user dissatisfaction". Besides Image Quality assurance, solving these 2 issues implies less user interactions and, then, fewer sources of error. During Large Format Z-Series printers development we had many user interactions. Some real customers "wishing quotes" about the possibility of automatic media identification were: "I don't have to select the media from a huge list of possibilities", "The printer remembers the last media I used, I don't have to select it every time I load a sheet of it", "I don't have to select a default media to clone from and probably make a mistake".

Also, once we know for sure the loaded media, the same information used to automatically detect it can be used for other purposes such as: Automatic predefined printing settings election, Automatic PPS (Pen to Paper Space) adjustment to optimize IQ and avoid head crashes due to cockle, Automatic media advance election, Automatic design of color printer parameters (color ink limits, color ink separations…) for new loaded media, Automatic cutter strategy election (we cannot cut Canvas paper, for instance), etc. We give special attention to the Automatic media color resources election for automatic profiling of new media (dry time, ink limits, number of color patches, type of colors to print, etc.). Any mistake in the paper election can make all the predefined settings totally useless.

Another problem solved is the use of wrong media type depending on the type of ink used. Currently we can find in the market printers with 2 main types of inks: dyes and pigments. There are specific papers for each type of ink: Sweallable and Porous. However, it is very easy to make a mistake and the IQ obtained is not as good as it could be. For instance, Sweallable media is designed for Dye inks; if Pigments inks are used, these don't penetrate the polymer and stay in the surface, provoking “breakable” surfaces of the prints.

This limitation has been known in the printing industry for very long time. For instance, Adobe explains in its courses that "Until printers can recognize the kind of paper loaded into them, all workflows are vulnerable to producing incorrect color if the user specifies paper type incorrectly, but this should be the only selection that could cause incorrect color conversions and multiple conversions." Within HP we have tried to know automatically the loaded paper in the past and several implementations have been put into the market. However, due to the type of detection done, the usefulness has been very limited. In the office environment where plain paper is used most of the times, basic type detection may work: “plain or gloss paper”. However, in the Creatives and professional Print Service Provider markets, the types of papers used are endless and a more robust automatic media detection is needed to increase user satisfaction.

Our Solution

We have demonstrated that by combining information obtained by the default sensors available in HP Large Format Printers (*SOL*: a spectrophotometer integrated inside the printer, and *Tetris*: a line scan and “glossimeter” sensor) we can automatically detect the loaded media in a printer using its color, IQ and surface physical properties. If the loaded media has predefined printing settings, these can be used. Besides, if the media is considered to be new, the printing settings can be automatically configured using the information from the 2 sensors. The following diagram shows the highlights of the algorithm workflow.

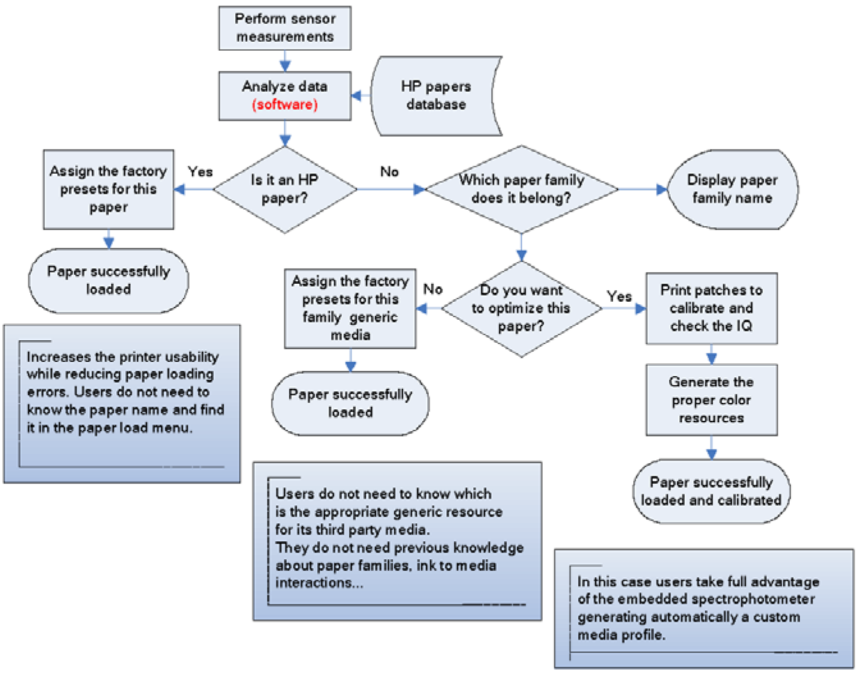

Figure 1. Automatic media detection and printing resources generation algorithm workflow

So the first approach works as an “*automatic media identifier*”. The main objective is to perform a non-destructive analysis of the paper and determine which paper it is. This means that the user is never asked about optimizing the paper. In a second approach the "*automatic media color resources generation*" is performed printing patches and using their measurements as feedback to generate automatically custom color resources. We define *paper family* as all the papers that share similar physical properties (for our printing applications) and then, same printing settings may be applied. Our objective is to classify any paper in its correct family.

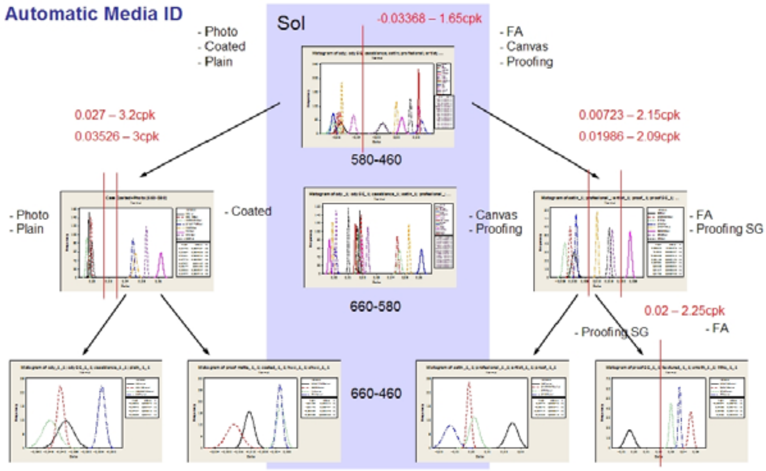

Figure 2. Papers families classification using spectral information

Evidence the Solution Works

Without the need of printing anything, just using SOL and Tetris measurements of the loaded paper surface we have been able to classify successfully 21 papers into 13 family types.

Table 1. Papers classification into family types

Family 1:	Technical papers	clear film
Family 2:	Technical papers	natural tracing
Family 3:	Technical papers	matte film
Family 4:	Technical papers	vellum
Family 5:	Technical papers	translucent bond
Family 6:	Photographic papers	glossy High Gloss
Family 7:	Photographic papers	glossy Semi Gloss
Family 8:	Plain paper	Plain
Family 9:	Matte Coated paper	proofing matte / coated / Heavy Weight Coates / super HWC
Family 10:	Canvas paper	canvas satin / canvas artist / professional canvas
Family 11:	Proofing paper	proofing Semi Gloss
Family 12:	Proofing paper	High Gloss proofing
Family 13:	Fine Arts paper	matte litho / textured FA / smooth FA

Competitive Approaches

The more information we can have about the media, the more the chances to automatically identify it. We could attach patterns (visible or invisible) or use different types of sensors to measure its friction, thickness, wet cockle while printing, glossiness, etc. Then, the challenge is to use the minimum amount and cheapest sensors to identify the highest number of papers without the need of pre-marking them. Being HP the only mass-market printer manufacturer with an integrated spectrophotometer technology puts us in an advantage position over the competition to improve the usability of all our printers and optimize automatically the image quality and color that our customers obtain under any circumstance, using any paper they want.

Status and Next Steps

Once we have been able to automatically detect the loaded media, we are currently working on the "*automatic media color resources generation*" and how to implement it in future LFP printers. It consists in printing and measuring a calibration pattern. SOL sensor provides color information for each ink primary and Tetris measurements help to reduce the primary ink amount before IQ artifacts appear (mainly bleed and graininess). Future LFP printers will include a PPS sensor. Thickness data will be useful to distinguish papers within the matte coated family without the need of printing color patches. There is a correlation between the thickness of the paper, its weight and, as a consequence, the maximum ink amount (or ink-limit) it can accept without IQ degradation.

7.2. HP IMAGING AND COLOR SYMPOSIUM (HPICS) PRESENTED POSTER

HP Imaging and Color Symposium
June 17-20, 2008 UC Berkeley

Automatic Media Recognition

PRESENTER

Luis Garcia

Large Format Printing Division

ABSTRACT

Every media type has unique physical properties. This forces us to define new printing pipeline parameters to optimize the image quality. Due to the endless number of settings, only a limited set of media types is characterized. Then, if the user loads one of these supported media and selects the corresponding, the predefined settings will be used and a correct Image Quality (IQ) will be obtained. However, bad IQ is typically obtained when user doesn't know how to select the right media type.
We have tried to automatically determine the loaded paper in the past, and several implementations have been put into the market with very limited success. Here we describe how using the embedded spectrophotometer and a line scan sensor (both sensors currently integrated in HP LFP printers), we can obtain sufficient information to automatically detect media type optimizing automatically printing pipeline parameters to ensure best IQ.

FOR INFORMATION

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invent

HP CONFIDENTIAL

1. Facing the problem

- Usability.

  Users are asked to select the media type from a list of more than 32 paper organized in more than 6 categories. It is difficult to find the desired media among these families and more so in the case of a third party media where there is not a matching name to look for.
- Image Quality (IQ) attributes that can be affected due to a wrong media type selection.
  1. Wrong color profile/map

     Color accuracy, contouring.
  2. Excess of ink

     Bleed, Coalescence, Cockle (may cause a print head crash), ink transfer.
  3. Lack of ink

     Poor colors due to not enough gamut.
  4. Ink-set

     Matte black on photographic papers (smearing, ink transfer).

     Photo black on coated papers (poor optical density).
  5. Media advance

     Banding, Grain.
  6. Cutter usage

2. Looking for a signal

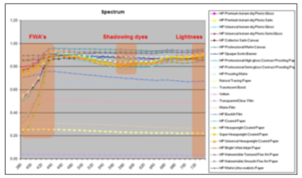


Figure 1: Spectral measurements of 24 HP media types done with Gretag Spectrolino

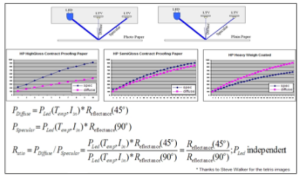


Figure 2: Tetris measurements of different media types

- In the first figure we can see what HP media spectral reflectances look like.
- We can define three areas containing the major changes that are related with the media physical properties.
- The first relates with the Fluorescent Whitening Agents (FWA), the second relates with Shadowing Dyes (SD) and the last one relates to lightness.
- For more information:

  Color Measurements on Prints Containing Fluorescent Whitening Agents, by Mattias Andersson and Ole Norberg, Mid Sweden University
- The second figure shows Tetris measurements on three media types. The specular measured values are greater, equal or lower that the diffuse depending on gloss, semi-gloss or matte surface type.
- For more information:

  Dot Placement and Auto Pen Calibration Summit November '06, by Steve Walker.

3. Studying the robustness

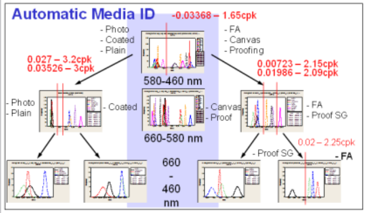


Figure 3: Spectral data analysis obtained with SOL (Spectrophotometer On Line)

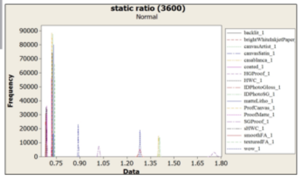


Figure 4: Tetris data analysis

- Technical media are identified via their lightness. As they are more translucent, Sol measures the black platen obtaining different grays tones for each media.
- As Sol is a UV cut solution whose measures are in the range of 420 to 700nm, we lose a valuable information.
- For the first partition we use the 580nm (valley due to SD) less 460nm measure (pick due to FWA) to make a first distinction among photo-coated and FA (Fine Art)-Canvas-Proofing.
- For the second partition we use the 660nm (related with Lightness) less 580nm value. Now there are four families photo-plain, coated, canvas-proofing HG and FA-proofing SG.
- In the last step we compare 660nm less 460nm. It helps to differentiate between FA and proof SG.
- After the spectral analysis, the Tetris sensor is useful to differentiate between photo SG-photo HG-plain, canvas-proofing HG.

4. Looking at the results

Family Properties

	FWA	Shadow. dyes	Lightness	Gloss ratio
Fine Art paper (2)	none	low	high	low
Canvas paper	mid	low	high	low
Photographic paper (3)	low	high	high	high
Proofing paper (3)	mid	low	high	high
Coated paper	high	high	high	low
Technical papers (1)	none	low	low	low
Plain paper	low	high	high	low

(1) 6 HP papers identified in this family
(2) 3 HP papers identified in this family
(3) Distinguish between gloss and semi gloss

Figure 5: Family common properties.

Identified Medias

Family 1:	Tech.	clear film
Family 2:	Tech.	natural tracing
Family 3:	Tech.	matte film
Family 4:	Tech.	vellum
Family 5:	Tech.	translucent bond
Family 6:	Photo	glossy HG
Family 7:	Photo	glossy SG / casablanca
Family 8:	Plain	plain
Family 9:	Coated	proofing matte / coated / HWC / sHWC
Family 10:	Canvas	canvas satin / canvas artist / professional canvas
Family 11:	Proof.	proofing SG
Family 12:	Proof.	HG proofing
Family 13:	FA	matte litho / smooth FA
Family 14:	FA	textured FA

21 papers analyzed
Tech: technical paper, FA: fine art p

Figure 6: Final classification

- Paper families share different physical properties allowing us to classify them in a robust way. This first approach would reduce the number of media types shown on the printer front panel or may help to display warning messages when the paper type mismatches.
- This classification is also important for 3rd party media types classification as they will share these properties.
- If we can characterize the media (HP media case) we can split some families enabling identification of individual types.

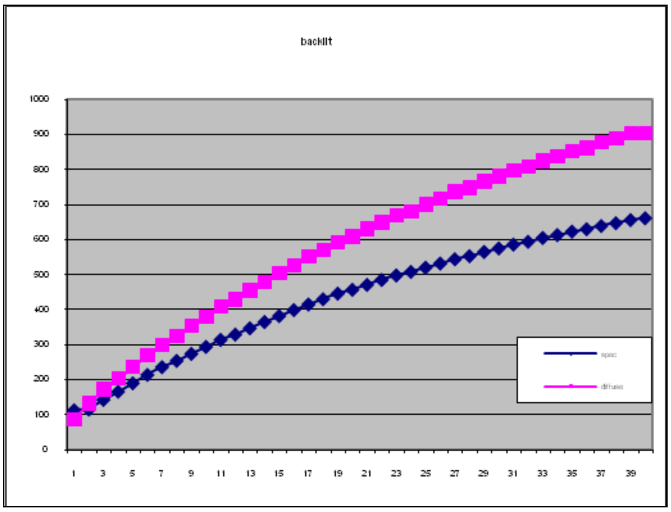
Path Forward

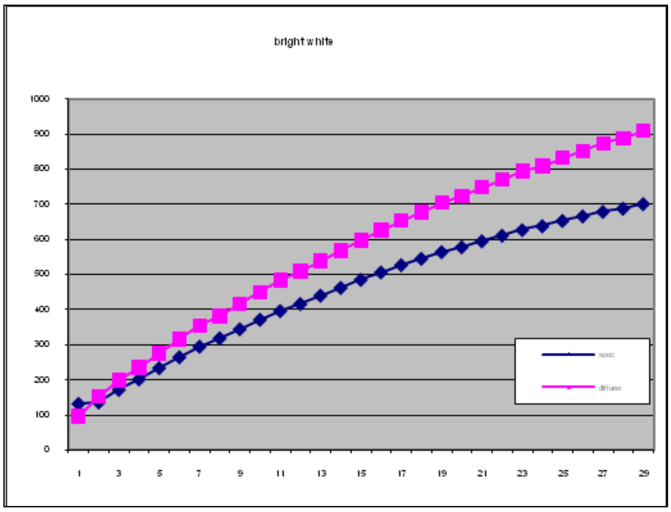
- Include UV spectral measurements as they provide the strongest signal. The Brego sensor may help as it is possible to acquire reliable data at 400nm.
- Since the coated family is sharing the same coating it is not possible to find any spectral difference or surface gloss change. We are confident that HPL's ECTris will help by measuring the paper thickness.

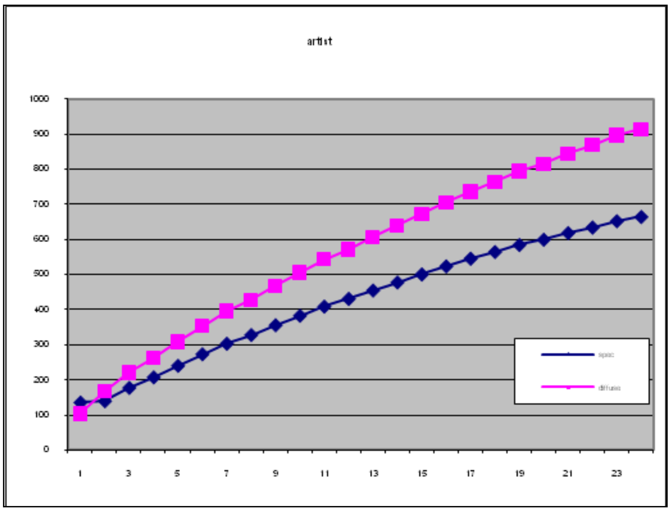
Acknowledgements

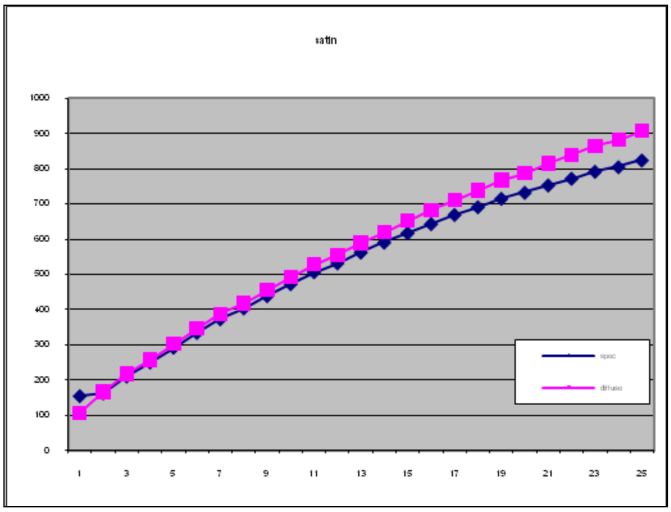
- The authors would like to thank Jacint Humet, Aleix Oriol and the rest of the team for their great support and advice.

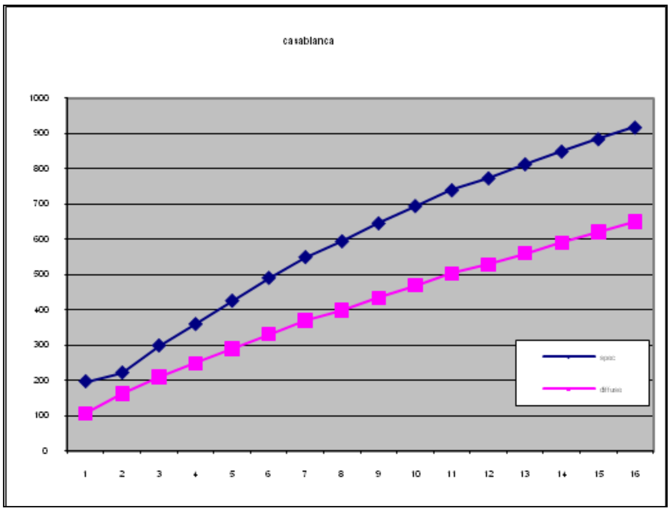
7.3. GLOSS METER CHARACTERIZATION ON ALL MEDIA

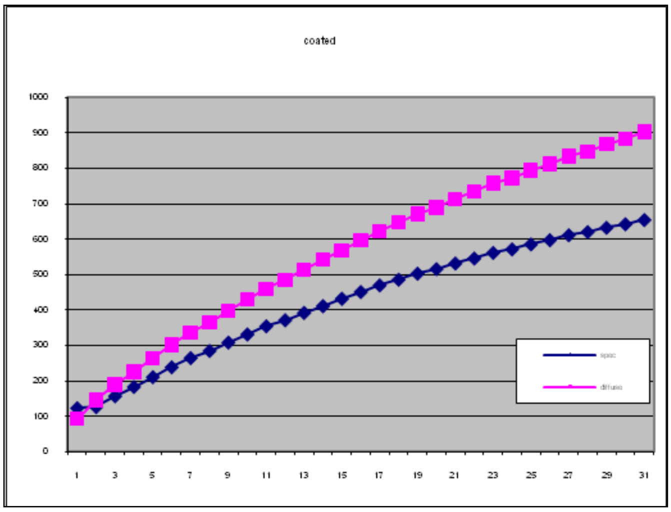


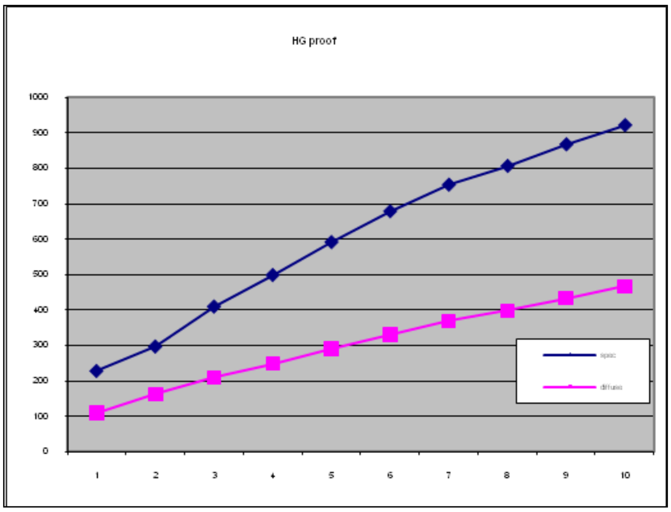


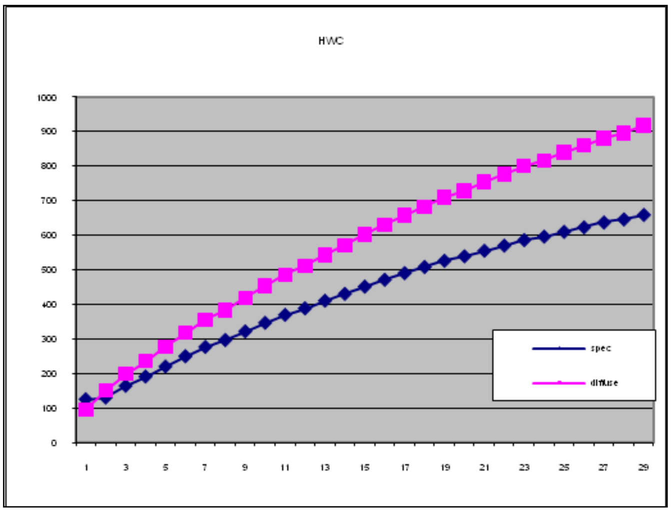


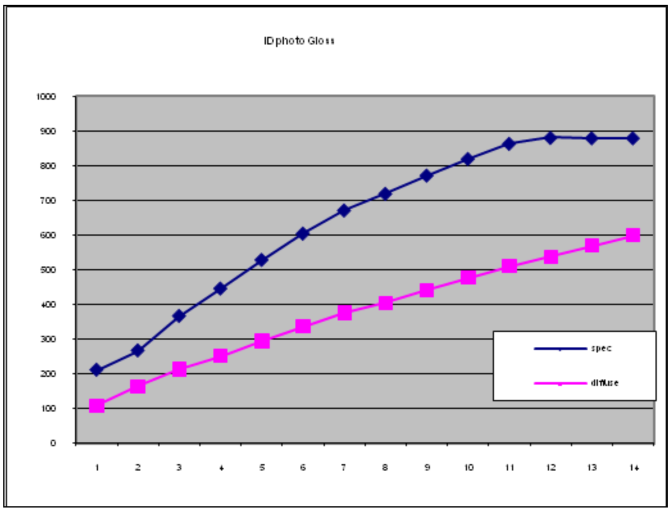


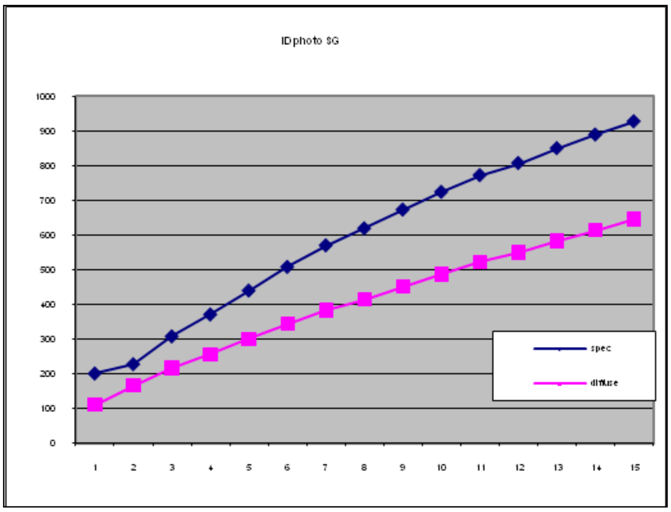


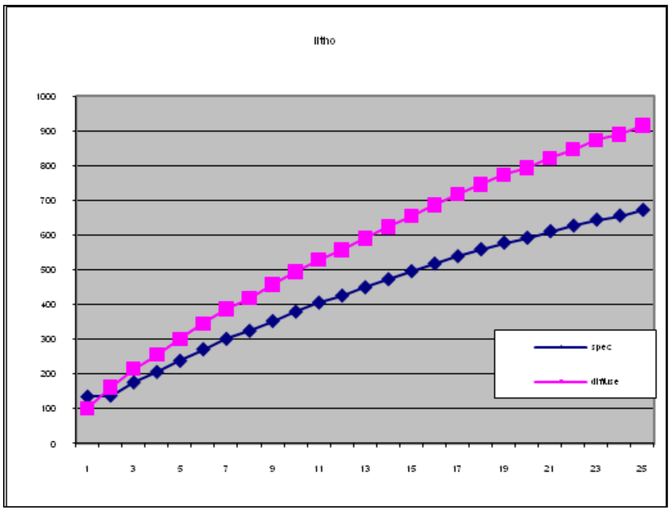


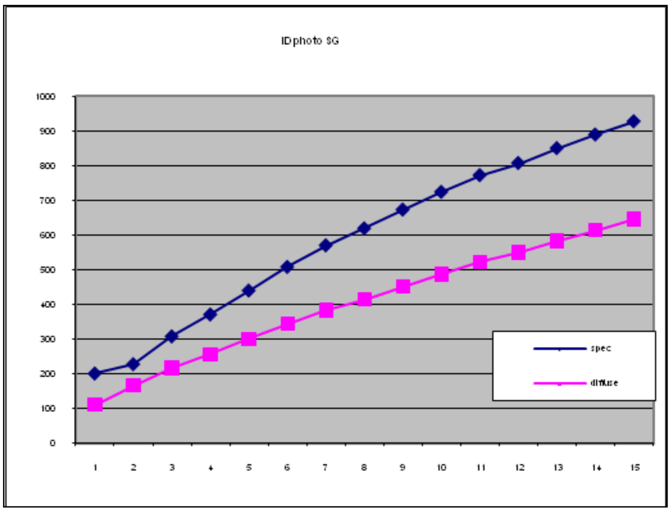

HG proof

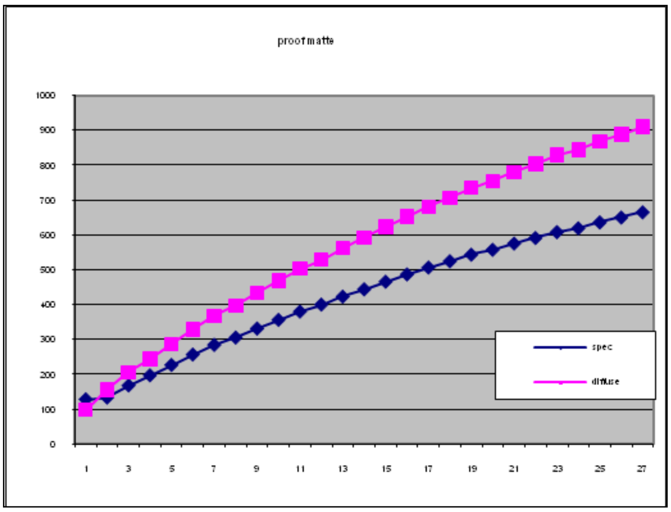

HWC
spec
diffuse

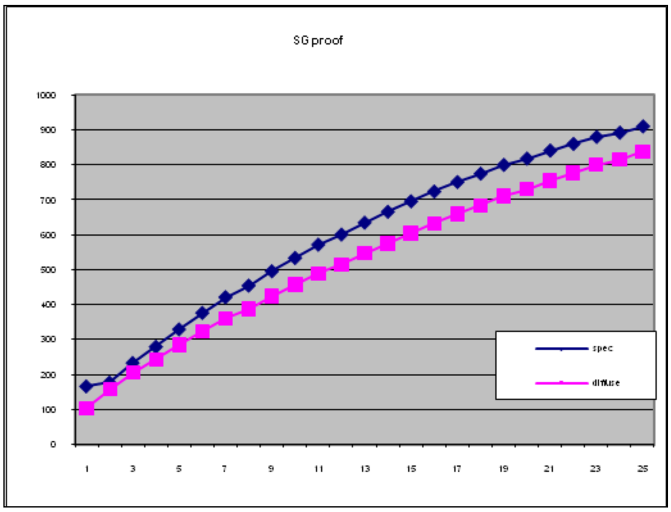

IDphoto Gloss
spec
diffuse

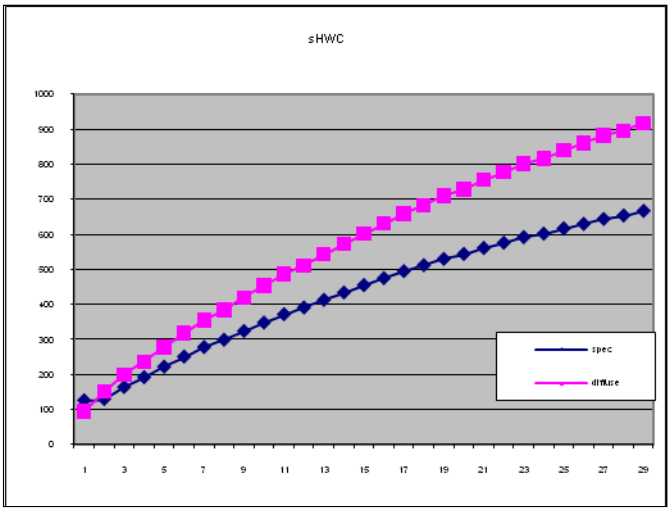

IDphoto SG
spec
diffuse

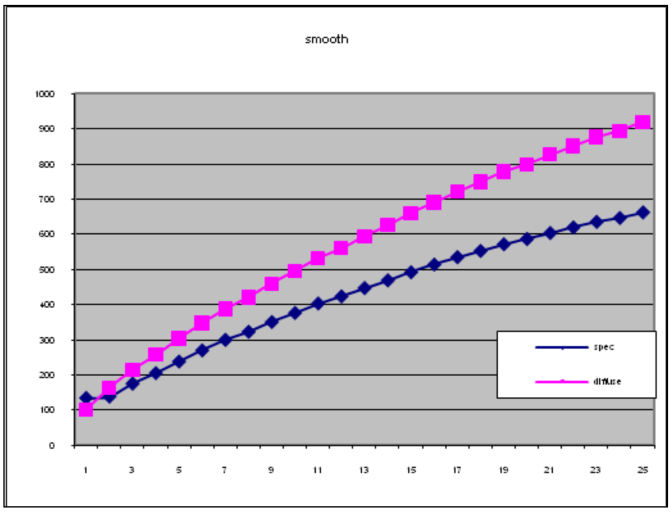

litho
spec
diffuse

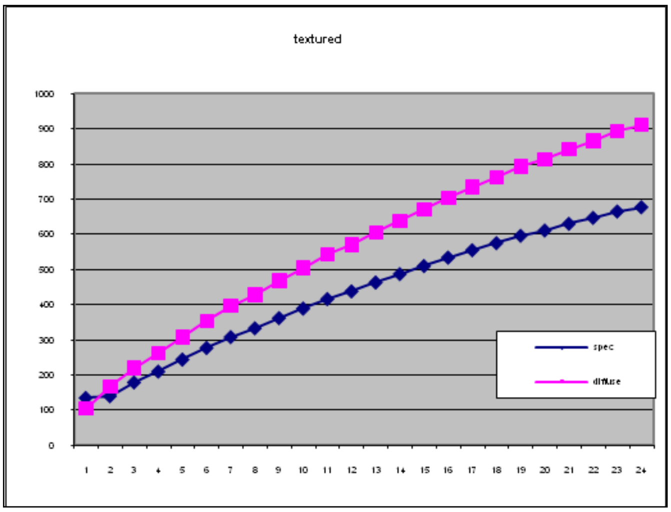

IDphoto SG
spec
diffuse

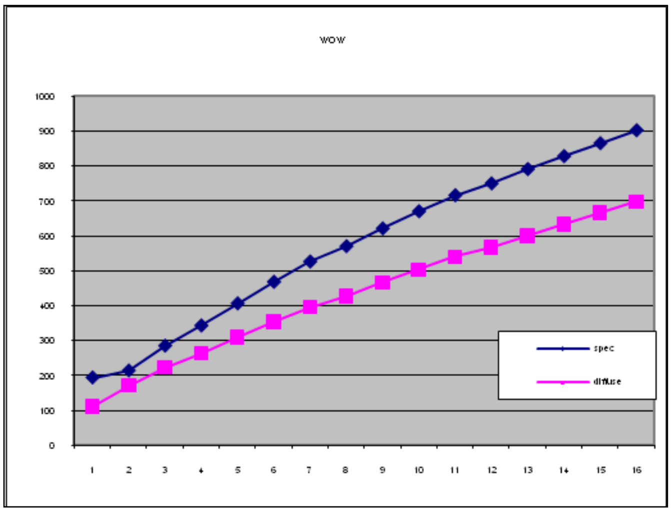

proof matte
spec
diffuse

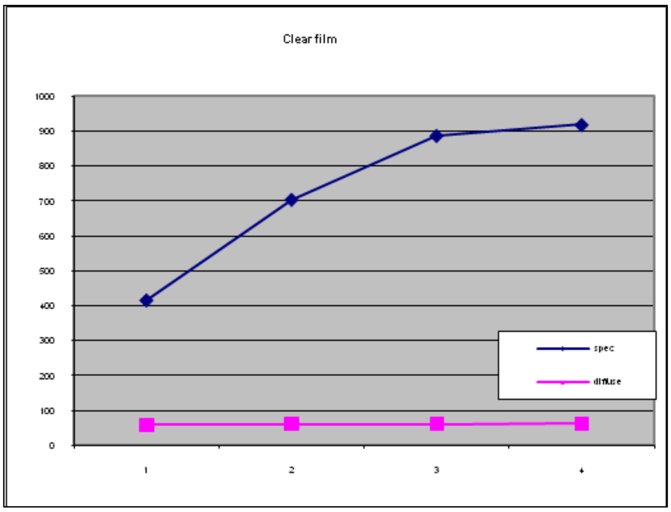

SG proof
spec
diffuse

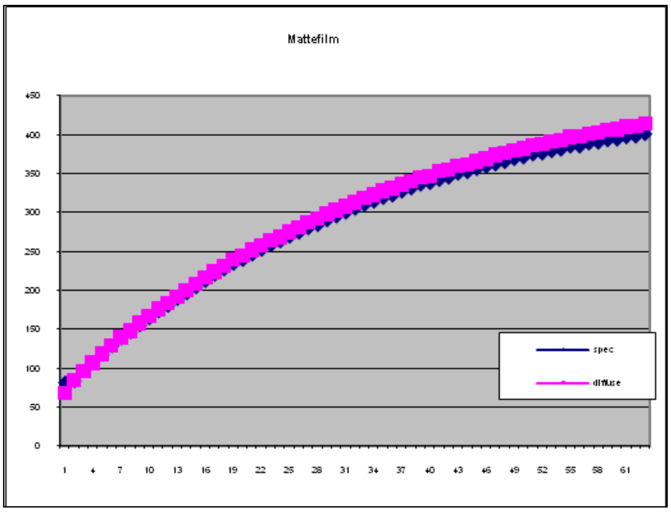

sHWC
spec
diffuse

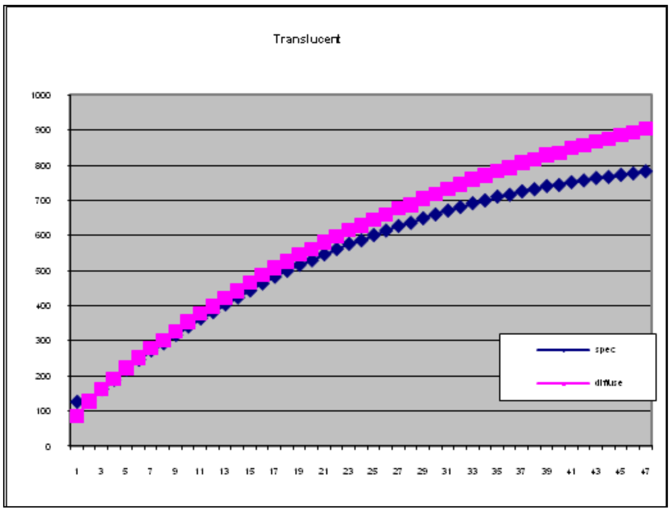

smooth
spec
diffuse

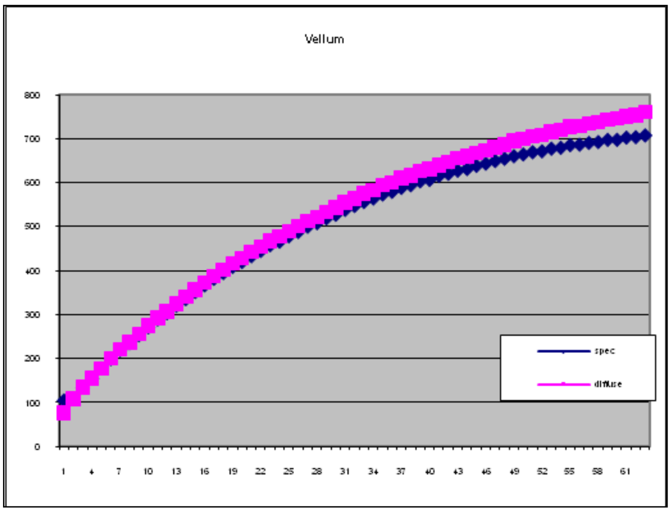

textured
spec
diffuse

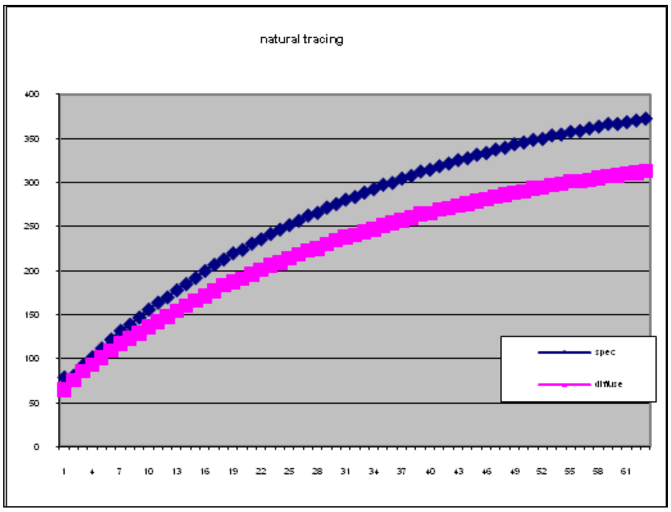

wow
spec
diffuse


Clear film
spec
diffuse


Mattefilm
spec
diffuse


Translucent
spec
diffuse


Vellum
spec
diffuse


natural tracing
spec
diffuse

7.4. GLOSS METER STATIC MEASUREMENTS

In static measurement mode, the sensor picks samples at a defined sampling rate on the same position. The only effect that we can see is the thermal drift.

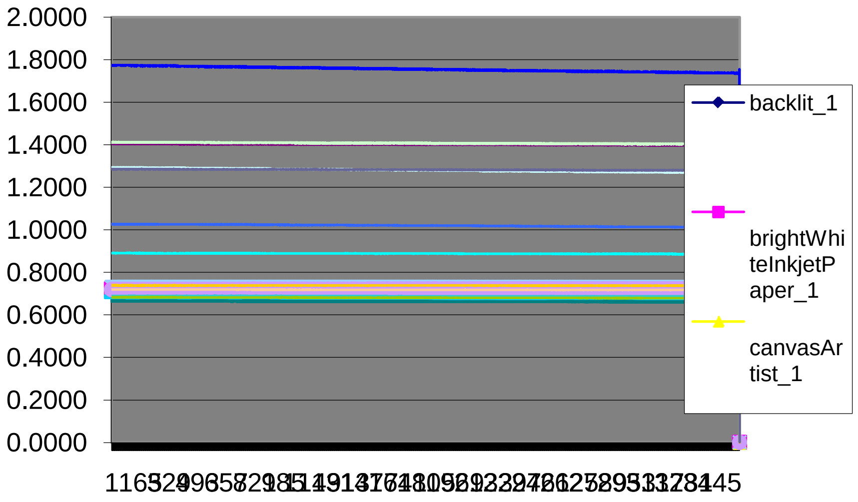


Figure 7-1 Gloss sensor static measurements

7.5. GLOSS METER DYNAMIC MEASUREMENTS

In the dynamic mode, the sensor picks amples at a defined sampling rate while the printer carriage is moving over the paper. In the next figure there are ten scans, separated by the red bars, of the same area of each paper.

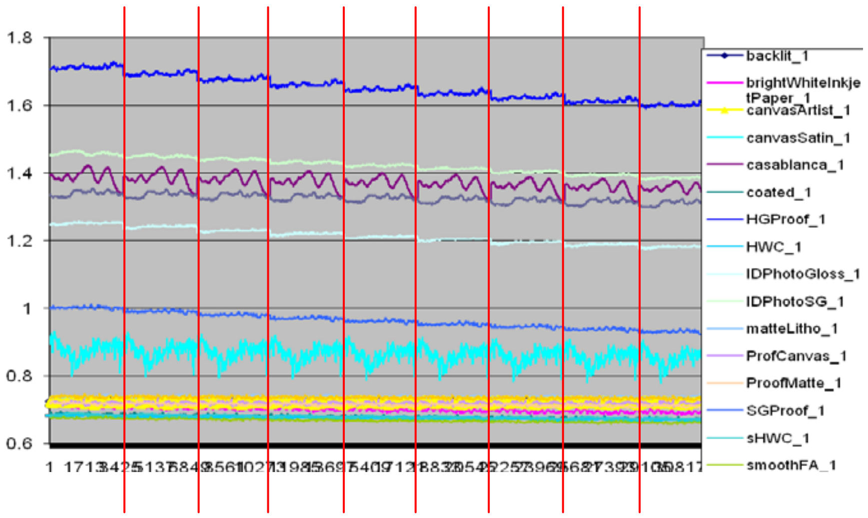


Figure 7-2 Gloss sensor dynamic measurements

Apart of the thermal drift, we can see that there are certain patterns depending on the media. In a deeper analysis we can see that this signals can be decomposed using the fourier method and its components are dependent as indicated in the next figures.

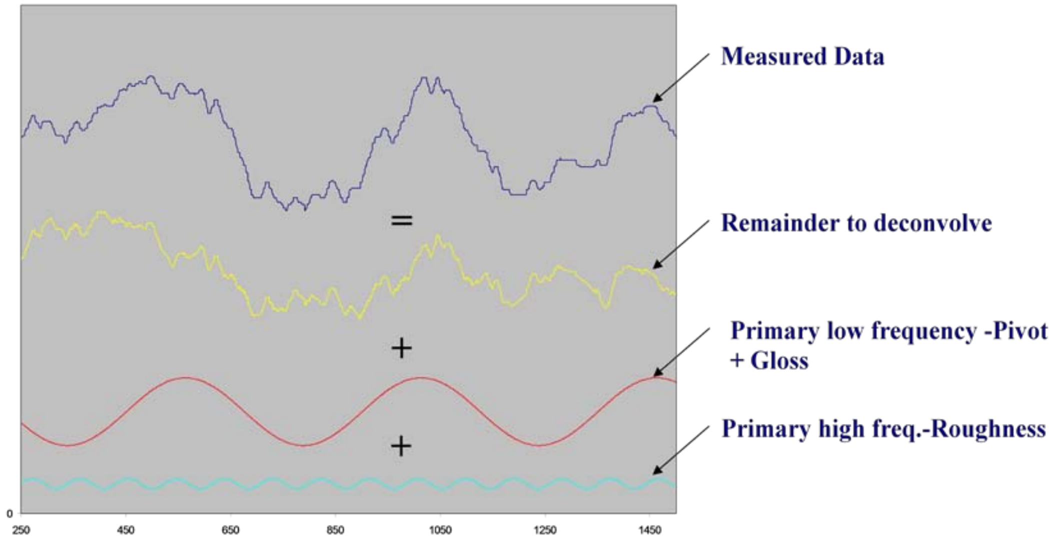


Figure 7-3 Gloss sensor signal decomposition

This can be understood with the next image.

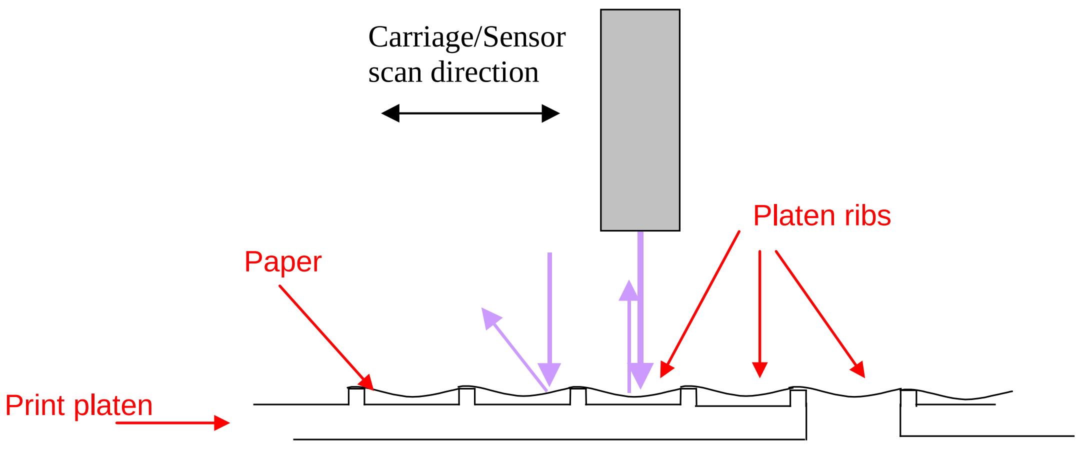


Figure 7-4 Gloss variability with position

7.6. MEDIAS UNDER D50 LIGHT AND UV LIGHT

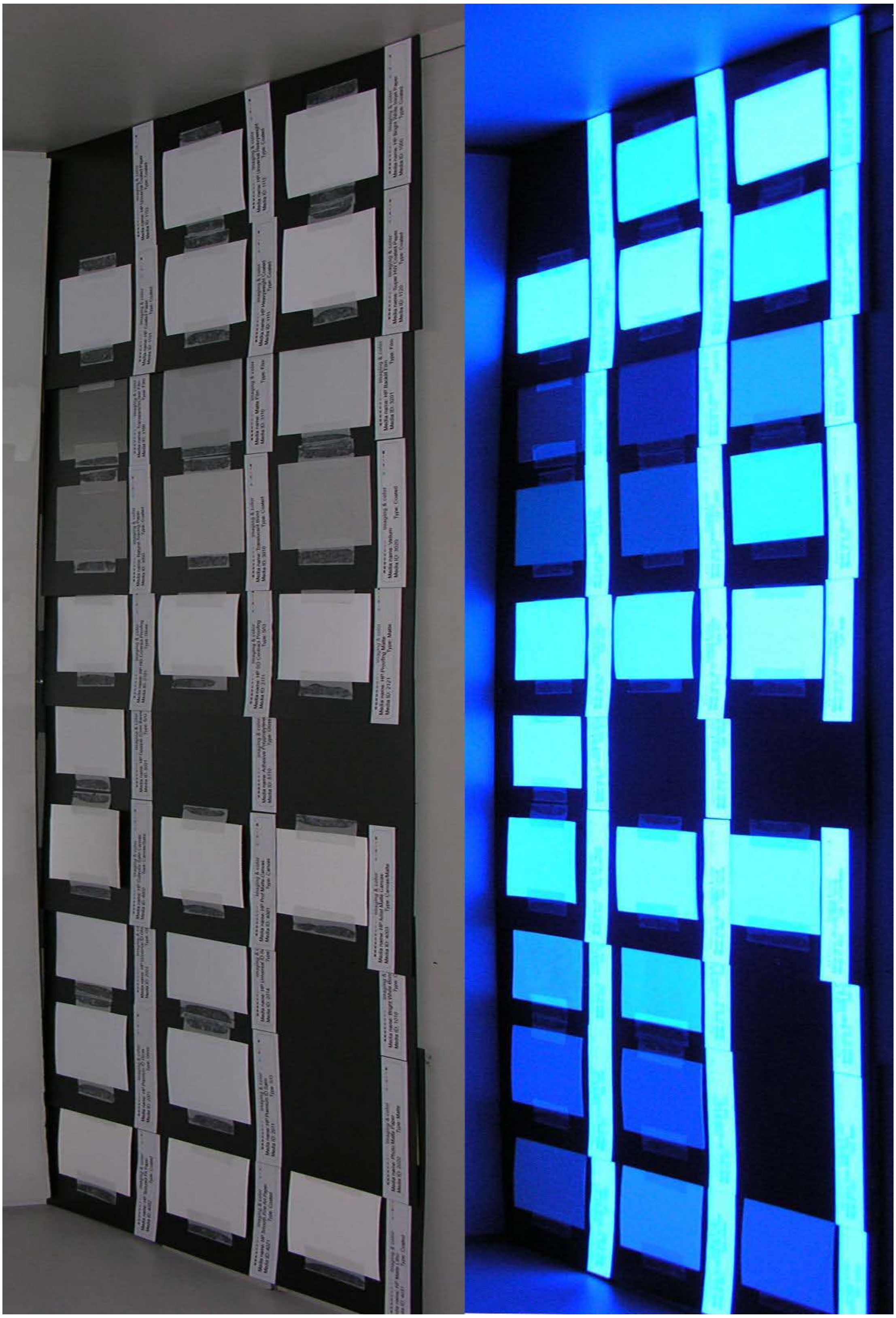


Figure 7-5 All medias D50 Vs UV light

7.7. MEASURES FROM MICRO-TRI-GLOSS METER

	x			stdev		
	20º	60º	85º	20º	60º	85º
backlit_1	1.0	2.1	3.3	0.0	0.0	0.2
brightWhiteInk_1	1.2	3.3	5.3	0.0	0.1	0.2
canvasArtist_1	1.2	2.3	3.2	0.0	0.0	0.2
canvasSatin_1	1.6	6.7	6.7	0.0	0.2	0.5
casablanca_1	18.5	40.0	83.2	0.2	0.3	4.3
clearFilm_1	143.0	146.0	88.2	2.7	1.6	4.6
coated_1	1.1	2.3	2.3	0.0	0.0	0.1
HGProof_1	31.9	52.5	87.1	0.3	0.2	4.6
HWC_1	1.1	2.3	2.1	0.0	0.0	0.1
IDPhotoGloss_1	29.6	48.4	86.3	1.0	0.3	6.4
IDPhotoSG_1	5.6	28.3	55.2	0.1	0.2	3.2
matteFilm_1	0.6	2.0	2.1	0.0	0.0	0.1
matteLitho_1	1.2	2.4	1.4	0.0	0.0	0.1
naturalTrancing_1	0.5	4.4	7.3	0.0	0.1	0.5
ProfCanvas_1	1.3	2.3	2.1	0.0	0.0	0.2
ProofMatte_1	1.2	2.4	1.8	0.0	0.0	0.1
SGProof_1	4.5	22.6	46.8	0.1	0.2	2.8
sHWC_1	1.1	2.2	1.4	0.0	0.0	0.0
smoothFA_1	1.3	2.6	2.5	0.0	0.0	0.3
texturedFA_1	1.3	2.5	1.0	0.0	0.0	0.1
translucent_1	1.1	5.7	11.3	0.0	0.1	0.5
vellum_1	0.8	3.9	3.9	0.0	0.0	0.1
wow_1	5.0	24.0	47.7	0.1	0.2	3.7

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