Multispectral Imaging and its Applications in the Textile Industry and Related Fields

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Abstract

The requirements of a multispectral imaging system are illuminated from an industrial point of view. Multispectral imaging finds its applications in the four basic fields archiving, faithful color image reproduction, color image communication, and color measurements. Example applications usually cover two or more of these four basic fields. They show the real need for multispectral imaging systems and the potential to reduce several color related problems to a minimum. Certain aspects influence the design of a multispectral imaging system. It must be stable, fast, easy to use, and safe against user mistakes. Multispectral images must be self-contained and need to be stored with varying levels of accuracy. Moreover, the lack of spectral output devices gets evident as the accuracy of the rendered multispectral images achieves a certain level.

Introduction

There are two traditional ways of acquiring color information. On one hand, spectral measurements can be made resulting in accurate color data but no information of the structure of the object. On the other hand, imaging systems such as scanners or digital RGB cameras can be used to capture color images in order to yield structure information, but the color quality is rather limited due to the mismatch between the device's spectral sensitivities and the color matching functions. Multispectral Imaging combines the advantages of both worlds, resulting in accurate, digital representations of the captured objects in terms of colors, patterns, and structure.

An ideal color image reproduction system would incorporate input and output devices that are fully capable of the spectral information. A print on paper would have the same spectral behavior as an original object such as a piece of fabric, and a monitor would produce the same spectral stimuli like the fabric under a given light source. In this ideal world, the print could not be distinguished from the original fabric, apart from its surface structure, and no person of any color vision would see any color differences between the original and the reproduction.

While spectral printing and spectral displays are currently under investigation at several research groups,[1–4] the currently available technology allows only the reproduction with three channels such as RGB (monitors) or CMY (printers). Though printers always use an additional black ink, and some print processes even have seven or more colorants, these have never been used to match a given spectral distribution. The additional inks are only used to increase the color gamut, i.e. the volume of producible colors.

Does it make sense to capture spectral information if it is to be reproduced only on three-channel devices? The answer is a big "YES" for two main reasons. First, color can only be reproduced accurately if it is captured by a camera with spectral sensitivities that exactly match those of the human eye (Luther condition). However, cameras never satisfy this condition exactly for technical reasons. Second, even if the Luther condition is satisfied accurately, the captured color and its reproduction are only valid for the lighting conditions under which the object was captured. If the image was taken with a Xenon flashlamp, a print on paper can only be correct under Xenon illumination. How large the color error for different illuminants is, depends on the properties of the original, and the ink and substrate used for printing.

In the following, applications of multispectral imaging using a multispectral scanner on the input side and conventional monitors and printers on the output side will be described. A respective multispectral communication system will be sketched. We will follow with a discussion of the demands and the quality of such a system.

Basic Applications of Multispectral Imaging

Applications of multispectral imaging systems can mainly be associated with one of the following four basic application fields:

1. Archiving
2. Faithful color image reproduction
3. Color image communication
4. Color measurements

Archiving

Archiving can have many facets. It can mean conserving the current state of an art painting for the future. This may include the recording of a spectral image of the painting at high spatial and spectral resolution, both in the visible range and in the adjacent UV and IR. It may also be desired to store relief information and gonio-spectrophotometric data (i. e. the variation of the spectral behavior with the angle of illumination or view). Here, much care is put on every single object to be archived, and very high demands are put on the stored data set in terms of the amount and accuracy of information.

Archiving in the automobile industry can mean to store all the design variants of all the car models that have ever been sold. Here, very different materials need to be archived side by side including varnish, plastic, fabric, leather, etc. The digital, multispectral archiving improves the availability of samples, and saves storage costs. It ensures that digital images which are drawn from a physical sample for various purposes are always identical since all are copies of a single original image. It eliminates the need to search for lost samples. It elevates the availability level to 100% even when the archive administrator is not available. Color and structure is very important, but the digitization process must be very simple, fast, and safe against failure.

Faithful color image reproduction

Very often, color images are recorded with the intent of reproducing them on paper, fabric, polyester film, etc. The desire is to make exact copies of the original, at least in terms of color. While the multispectral image capture provides digital data which are free of systematic errors, the output color quality is limited mainly by the fact that the determination of the colorant output is merely based on tristimulus calculations. Hence, the reproduced colors only provide a metameric match which is accurate only for a single illuminant and the used standard observer.

For prints, the illuminating lamp inherently has large influence on the overall color balance and the spectral weighting of the mixed colors. The light source which was computationally used for the spectral weighting must spectrally match the lamps used for illumination of the prints. Note that for printing, the illuminant needs to be discounted from the data sent to the printer, since the illuminating light is responsible for the appearance. In some cases, it is very difficult to get equally looking prints from captured originals. This is a reason to reproduce color images on a monitor. Though monitors are limited to tristimulus colorimetry as well, the illuminant is less a problem as it does not need to be discounted. The display is self luminous and outputs the color balance for that lightsource which was put into the calculations.

Another application is to use the multispectral image capture system as an input device for further image processing. For example, existing dessins can be captured, and then new designs are created by picking colors within one image, and transfering them to certain parts of another image. Third party software is available for this purpose, where the number of used colors can be automatically reduced from millions (24 bit RGB or Lab) to some tens in order to help the recoloring process.

Applications of accurate color prints as well as accurate display reproductions can be found in the textile and apparel industry.

Color image communication

If color images can faithfully be reproduced at one place, the same can be done at other places as well. A basic requirement for this is that all reproduction devices are carefully set, well characterized, and color managed, and — extremely important — the viewing environment ist well-controlled and set to the same conditions. The importance of keeping all these requirements identical at every point of color assessment can be compared e.g. to the telefax communication system. Documents can only be shared with partners who have fax devices obeying the same standard.

The accuracy of keeping the viewing conditions must be very high. E. g. it is not sufficient to render a multispectral image for standard illuminant D65 and compare with an original viewed under a daylight simulator tube. Particularly synthetic fabrics display a strong metameric behavior which can lead to clear differences between display and original.

Multispectral images can be communicated across the Internet. When the described preconditions are adhered to, professional designers are enabled to quickly communicate design wishes and demands. Instead of the need to react to comments such as ”more frosty”, the color is seen faithfully on a monitor with both partners. Moreover, color can be modified deliberately by the recipient and returned to the sender, so that e. g. a supplier knows accurately what the customer wants.

Color measurements

Since multispectral images contain spectra for each pixel, such a system can also be used to take spectral measurements. Using a multispectral imaging sytem for measurements instead of a spectrophotometer has two strong advantages:

1. Measurements can be taken of even patterned or structured objects which cannot be measured by spectrophotometers.
2. The measurement can be combined with a faithful visualization of the object.

The first advantage is implicitely being used when a structured object is captured and displayed on a screen. Using a spectrophotometer, it is just not possible to get a faithful reproduction of multi-colored objects. Moreover, making use of image processing in order to separate different structures, it is possible to determine average colors across certain, arbitrarily shaped regions.

In many cases where the accuracy of color is a major qualiy criterion, companies do not rely on color measurements, but make use of visual assessments. Examples can be found e. g. in the textile and in the automotive industry (varnish). There are several reasons for this,[5] one being the mismatch between the standard observer and the individual, or even average, color vision. Another is that particularly the look of fabrics is determined by much more than just their color. We have seen examples of fabric sample pairs which have more or less the same tristimulus values, but look completely different. For example, one of them appeared precious and brilliant, while the other looked dull and flat. Here, the second andvantage comes into play, since the multispectral image carries these non-color related attributes as well.

Moreover, the illumination/vision geometry of a multispectral imaging system is more flexible. Hence, the overall appearance of an object can be captured just like a human looks at it. Spectrophotometers, on the other hand, only have a limited choice of geometries (45/0 or diffuse) and make no difference of the orientation of the object. Fabrics, however, can look quite different e. g. if they are rotated by 90°.

Textile related examples

Printing of fabrics

It is a general wish to be able to duplicate originals such as fabrics, paintings, photographs, etc. For photographs, the usual color workflow of combining e.g. a characterized flatbed scanner and a characterized printer and feeding the raw scanner data through a color management system, delivers good results. However, this is not the case with original material other than film, particularly with more than three colorants/dyes or pigments.

A multispectral scanner is able to record images without systematic errors, as the standard observer is introduced accurately. Then it is possible to compute printer driving signals (RGB or CMYK) which lead to accurate results for the standard observer and one illuminant.

Such reproductions of fabrics are distributed e.g. by a fabric manufacturer to his customers if not enough sample fabric is available. Even if there was enough fabric, printing the samples is much easier and cheaper than cutting the fabric into pieces. But very often only small textile samples are available.

Reproductions can also be made indirectly by means of CAD programs. Instead of capturing whole textiles, single yarn colors can be measured as well. They can be used to construct weaves and bindings and to simulate the appearance of a newly designed fabric. The simulation can be printed in order to give a realistic representation of the ideas of the designer. The advantage of using a multispectral scanner to record the yarn colors versus using a spectrophotometer is that the illumination/capturing geometry is more flexible and

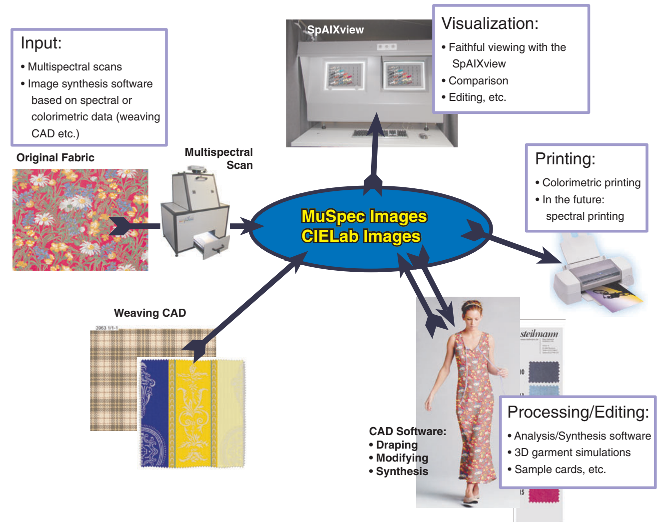

Figure 1: *MIC: Multispectral Image Communication System*

can be made the same as with recording whole images. This often gives results that correlate better with what human persons see than the outputs of spectrophotometers.

A second indirect way of reproducing fabrics is to simulate complete garments from simple fabric images. So-called ‘draping software’ can map the flat fabric image onto a three dimensional garment such as a skirt. If the CAD program processes the colors in a defined way, the simulated garment has the same color quality as the original fabric file. In ref. 6, example images can be found.

Exchange of design drafts

The processing and reproduction of captured fabrics as described above can be extended to a complete design and communication system (Figure 1). The recorded samples are faithfully displayed on a monitor, modified, combined with other samples to new designs. New fabrics can also be designed from scratch, but using existing colors. Here, a well-controlled viewing environment is a basic requirement to finally get accurate colors. Design drafts can be forwarded to customers or suppliers if they are equipped with the same controlled viewing environment. A fabric manufacturer’s customer can send his ideas by multispectral image files (“Look, we would like to have such designs, but with the actual fashion colors”). A multispectral imaging system can conserve the yellow or red tint of an autumn leave. A garment manufacturer can study the appearance of non-existing garments by draping even fabric simulations onto three dimensional figures.

The whole design process can be short cut by using digital color image references. This can also save enormous amounts of shipping and travelling costs.

Quality control of embroidery

In the lace and embroidery industry, it is state of the art that the colors of their products cannot be measured reliably. Hence, the only way of controlling the color quality is visual assessments. Considering that e.g. a bra has 15 different parts made of different material (embroidery, plastics, metal, polyamide, polyester, rubber, etc.) it is not simple to get the colors of all these parts matched.

When a new color is defined, usually all suppliers of the different parts receive a dyed fabric sample. Then, they try to reproduce the given color on their material with a laboratory dye. It is clear, that a dyed embroidery looks quite different from a plain fabric. The same is true for e.g. the plastic parts. The lab dye is then submitted to the customer, i.e. the manufacturer of the bra. When all the dyed parts are put together, it is sometimes recognized that the wanted color is not achievable on all materials. So it needs to be redefined, sometimes in a way like: “OK, we take that pink, but slightly yellower”.

When the ware is ordered, each of the suppliers has to recalculate his recipes. Finally, when the first bulk is dyed, a sample is cut from the embroidery and sent to the customer for acceptance. If all the parts match in color, the bulk is shipped. If they do not, the manufacturers are asked for redyeing the already dyed ware. After doing so, once again a sample is cut and sent to the customer. When finally the ware is accepted, then frequently with an inaccurate comment like “please go no redder”.

All this process is lengthy, expensive, sometimes annoying. The visual pass/fail decisions are not always reproducible. Due to the necessary transfer of the assessment samples, mostly between continents, it typically takes five working days before a customer response is available. Within this time, the produced bulk is occupying storage space, and the redying process is sometimes repeated up to five times.

When we consider the same scenario using a multispectral image communication system, the complete process is cut down from weeks to days. When the first dye of a new design is produced, it can be multispectrally imaged immediately, and sent to the customer. The customer can compare and judge quickly, and provide his feedback. The same can be done when a bulk is produced. Once again, the cut sample can be imaged and displayed on the screen alongside with the image of the reference sample. If the difference is acceptable, the file is sent to the customer for approval. The great advantage is that all the samples can be easily captured under the same, controlled conditions, and they are visualized under the same conditions. This makes the judgements much more reliable and reproducible.

Another advantage is that the supplier who first delivers the lab dye, has the biggest chance of defining the color reference. Due to the much shorter production cycle, it is the customer's advantage that he needs to accept suboptimal dyeings due to time constraints in less cases.

Virtual color reference sample

An economically important field is the color faithfulness of mail order catalogs. They contain usually thousands of color images which are all taken as the basis for a consumer's judgement of favor for a certain color. Very much effort is necessary in order to reach the level of faithfulness we are all familiar with. Though often enough the color of an ordered shirt does not match its catalog image, even a spectral print would not solve all of the problems.

A major cause of ‘all the evil’ is that we want a catalog picture to look nice and beautiful, so that we can imagine ourselves as pretty and good looking if we would wear those clothes. Consequently, the goods are not photographed in a studio by just laying them flat on a table. The venders usually employ excellent photographers who, together with a troup of beautiful models, are being brought to some nice and moody location somewhere at a beach in Trinidad or South Africa. They pay the highest attention to catch the last ten minutes of moody sunset light in order to bann artistic pictures on the film. They do not care about the faithfulness of colors. Since they are artists, they do not want to be bothered by mundane businesses such as color management or color reliability.

As a consequence, many persons make their living by correcting the colors in the photographs so that the pictures match the original pieces as close as possible. This is a place where some major problems are introduced. How do the retouching persons decide which are the right colors?

First of all, they need the original garments for comparison. These are illuminated by the graphic arts standard light, D50. The monitor on which the pictures are displayed, however, is rarely set to D50, mostly to 6500K correlated color temperature. Under these circumstances, it is very difficult, to modify an image on the different medium ‘monitor’, which has a cooler looking color temperature, so that a print, which will be made later, and which has colors metameric to the originals, should match the original.

Returning to multispectral imaging, unfortunately it is not yet possible to capture such scenes multispectrally. However, pieces of all the photographed garments could be digitized multispectrally in addition to the photo shootings so that digital color reference samples are available right after the photo sessions are finished.

This introduces a number of advantages: The unique garments do not need to leave the vender's house. The color reference samples are available on the same medium like the images to be retouched. Henceforth, the retouching process is simplified as there is no need to compare the monitor with some reflective object. Moreover, the transfer of color from the reference image to the garment picture can be automated by some sophisticated software. Multiple persons can do the retouching at different locations since the references can easily be duplicated. There are even more, new possibilities like archiving etc.

Requirements of a Multispectral Imaging System

Having the described applications in mind, certain aspects influence the design of a multispectral imaging system.

- Stability The main goal of a multispectral imaging system is the accurate reproduction of objects with all their colors on a monitor or on print. Hence, high demands are given for the stability of the devices and the quality of the color management.
- Variable level of accuracy: The level of accuracy of the stored multispectral images can range from very high (e.g. for the archiving of art) to rather low, if images need to be transmitted over narrow channels such as the Internet. The compression technique needs to be fittable to very different applications. Various efficient image compression methods are needed, ranging from a reduction of the number of multispectral channels, over reduced bit-depth of the channels, up to spatial compression in cases where the image structure is not too important.
- Simplicity of usage and safety against user errors: The users often do not have much know-how in color imaging or color measurement, hence a simple user interface which prevents the negative influence of user mistakes, is mandatory for industrial applications. Moreover, It must be possible to convert the multispectral images to other standard data formats very easily.
- Multispectral images must be self-contained. All the information needed to reconstruct a spectral image must be stored within a single data file. If a user opens the file and has preselected an illuminant, the image must be automatically displayed, regardless of the origin of the image, the type of multispectral imaging system, the type of data, the compression type, etc. For scientific purposes, it must be possible to store additional information in the file, such as the spectral characteristics of all the used components, so that a sophisticated user or software program is able to implement different spectral reconstruction methods.
- Speed. For industrial applications, the speed of image recording and image rendering is very important. If a user is doing multispectral image captures all day, the value of a multispectral imaging system is directly related to its speed. This is also true when multispectral images are worked with on a display, rendering them for different illuminants, comparing different bulk samples with a reference, etc.

The Color AIXperts SpAIXscan is designed according to these demands, and therefore it incorporates a fixed geometry, including illumination, filters, optics, etc., and has a simple user interface. Moreover, the accurate rendering of multispectral images is covered by the SpAIXview multispectral viewing workstation. Hence a multispectral image with 6 million pixels and 16 channelsm, where the reflectance spectrum of each pixel is reconstructed in 5nm steps from 380–720nm, can be captured and accurately displayed within two minutes.

Problems of faithful image reproduction

Color management

The basis for accurate color reproduction is a well-working color management. Every printer and monitor must be colorimetrically characterised on a regular basis. All the available standard characterisation tools are using D50 as the reference illuminant. This means that e.g. color prints are only accurate if viewed under daylight of 5000K correlated color temperature (CCT). However, this condition is not controllable and virtually never available. The available daylight simulator tubes only have a very limited similarity with actual daylight. Their spectral power distribution shows clear peaks, as opposed to 'real' D50, and the CCT itself often deviates considerably from 5000K. Hence, actual conditions for accurate viewing are not available.

Though D50 can be treated as a working compromise between daylight and the normal room illumination with tungsten lamps, for professional applications, this compromise ist not accurate enough.

Some of the characterisation tools provide the possibility to use different illuminants, but it is the responsibility of the user to choose the right settings. Moreover, the available ICC color management ist optimised for reproducing 'good images' (keeping a good contrast, preserving the structure both in the highlights and shadows, etc.), but not for 'accurate color'. This needs to be taken into account.

The viewing environment

As was mentioned before, the reproduced images on print or on a display are only valid for certain viewing conditions. This turns into a serious problem if prints are to be compared with monitor images, since the viewing conditions are extremely different. A monitor is self luminous and needs to be viewed in a dim surround. A reflective print on the other hand, needs external light to be visible. Hence, it is not possible to compare a print with an image displayed on a normal monitor. Either the print would be hardly visible or the monitor would have a bad contrast if it is illuminated externally.

The minimum requirement for comparing a print with a display is a standard light source (e.g. D50) and a monitor set to the same color temperature. However, since none of the devices can usually be put exactly to the wanted settings, it is hard to make them match. Second, a monitor with a CCT of 5000K always looks yellowish, since people are used to monitors appearing much 'cooler', and do not adapt completely to the white point.

A way to overcome all the problems of the viewing environment is to use a specialised viewing workstation as described above.

Individual color vision

Colorimetry deviates from the other measurement sciences in that it is based on the human color vision. Only what a human person sees or does not see is essential. Hence, all the standards for color measurement are based on the definition of a standard observer. This introduces two major problems:

1. Human persons do not have the same color vision. Though the differences are not too large, it is known that some female persons have a much better color discrimination ability than an average person. Moreover, the retina turns yellow with ageing, and hence modifies the spectral sensitivities.
2. The locus of sharpest vision on the retina is dyed yellowish. This has the consequence that the spectral sensitivities are depending on the angle of subtense of a colored spot. For this reason, the CIE has defined both a 2° and a 10° standard observer.

Fig. 2 shows the color matching functions, i.e. the spectral sensitivities, of the 2° and the 10° standard observer.

In practice, one has to decide which of the standard observers to take, and additionally, the question is still if any standard observer resembles the color vision of the participating persons accurately enough. Fig. 3 shows the reflectance spectra of two beige samples which have almost identical tristimulus values under illuminant D65 using the 2° observer. When persons are watching the respective physical samples, each of which has a size of approx. $10 \times 10cm$, under a daylight simulator lamp from a distance of $1m$, they observe a strong greenish cast of the sample with the dashed spectrum. This is a case where the standard observer is not sufficiently accurate, even on average.

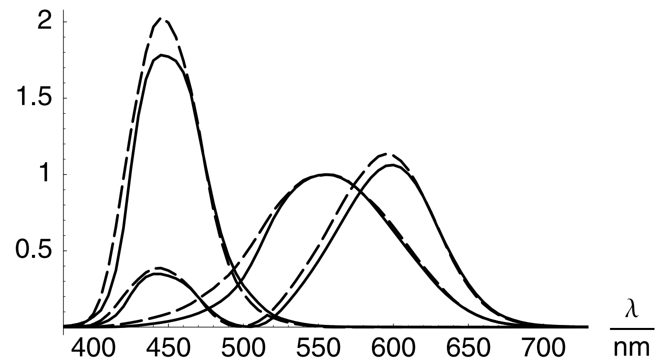

Figure 2: *Color matching functions. Solid lines = 2° observer; dashed lines = 10° observer*

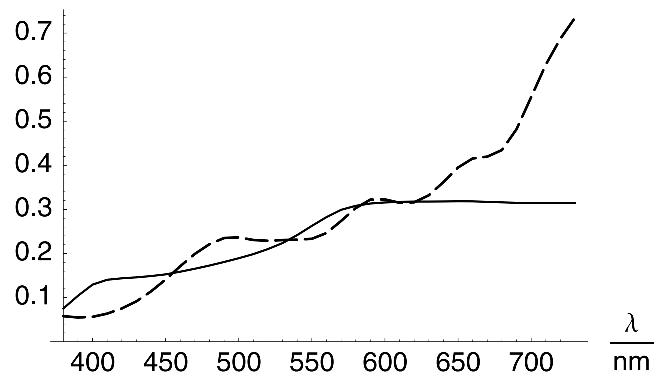

Figure 3: *Two samples of beige color.*

Conclusions

In this paper, the requirements of a multispectral imaging system have been illuminated from an industrial point of view. Multispectral imaging finds its applications basically in the four fields archiving, faithful color image reproduction, color image communication, and color measurements. Example applications usually cover two or more of these four basic fields. Examples related to the textile industry have been presented. They show the real need for multispectral imaging systems and the potential to reduce several color related problems to a minimum. Certain aspects influence the design of a multispectral imaging system. It must be stable, fast, easy to use, and safe against user mistakes. Multispectral images must be self-contained and need to be stored with varying levels of accuracy. Moreover, the lack of spectral output devices gets evident as the accuracy of the rendered multispectral images achieves a certain level.

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