

# Using ICC Profile for Determining Pigment Concentrations

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## Abstract

*In this research, ICC profiles were used to estimate pigment concentration for a specific set of pigments in an image. The spectral reflectance of any pixel was reconstructed based on pigment concentrations. Thus the colorimetric values under different viewing conditions could be calculated based on reconstructed reflectance spectra. Pigment concentrations were estimated using a look up table; then another look up table was utilized to estimate the colorimetric values under the desired viewing condition. Hence, two look up tables were built to connect concentration and CIELAB color values based on one-constant Kubelka-Munk theory for opaque layers. Out of gamut color as well as non-linearly between concentration values and CIELAB coordinates were accounted for. Reflectance data for Xrite ColorChecker classic and SG were used to evaluate the workflow. At the end ICC profiles are applied to a test image of a painting to estimate its appearance under different light sources. This technique is useful for simulating a work of art's appearance as an aid for lighting design using common picture editing software such as Photoshop.*

## Introduction

The influence of viewing condition on object appearance is well discussed in classic color science [1-3]. This change in appearance is modeled by different physical and statistical techniques [2, 4, 5]; however, most of these methods are not used ordinarily due to their complexity or long processing time. Spectral color reproduction and pigment identification algorithms are good examples of complicated physical or statistical algorithms. Although many assumptions are made to make the methods more practical and easy, the use of such methods often is limited to scientific programming languages such as Matlab or C++ and by skilled individuals. In addition, executing these methods is not practically possible on the high-resolution images with millions of pixels most of the time.

Look up tables (LUTs) are usually considered as a viable solution when input and output spaces cannot be connected algorithmically. Basically, by using LUTs the complexity is compensated by calculating the corresponding values in both spaces for some known points in the LUT nodes. The neighborhood pre-calculated nodes are used to estimate any new point within the destination space using linear or non-linear

interpolation methods. For instant, LUTs are widely used in converting colorimetric coordinates to CMYK values for printers [2, 6, 7].

Today the most common approach to implementing color image processing is via color management, ICC profiles, and color engines using Photoshop. As far as ICC profiles are applied to images, they are implemented and optimized for linear interpolation calculations. Consequently, ICC color management system has the potential to be applicable in other aspects of color conversions other than just colorimetric transformation. Furthermore, ICC color management is contained within the most popular image editing packages like Photoshop; thus, it can be used by non-professionals. In this research we tried to introduce and evaluate ICC color management as a computational tool to estimate the colorant concentrations for colorimetrically-imaged artwork.

## Theory

The workflow used in this research is shown in Figure 1. The device dependent color coordinates in the first image are converted to CIELAB color space for D50 illuminant using an input ICC profile. CIELAB coordinates are then converted to the concentration of a set of known colorants using an abstract ICC profile at which both input and output color spaces are CIELAB space. Since the mixture of three primary pigments is considered for colorimetric match, three predefined channels in CIELAB ICC profile can be utilized for the concentration of each primary. Accordingly, in the concentration space, the image does not have its correct appearance because CIELAB channels are replaced by colorant concentrations rather than colorimetric data. And as the spectral properties of the pigments are already known, the spectral reflectance of each pixel can be calculated using a spectral mixing model. In other words, concentration space can be assumed as a spectral space as well. Based on reflectance curve for each pixel, the colorimetric values were calculated for a desired viewing condition using second abstract ICC profile. The output image can be shown in the output device using appropriate ICC profile.

However, there are some limitations in building the LUTs based on the structure of ICC profiles, which will be discussed in this paper. The main steps of this procedure are building 2 LUTs to convert concentration to CIELAB space in order to make two ICC profiles.

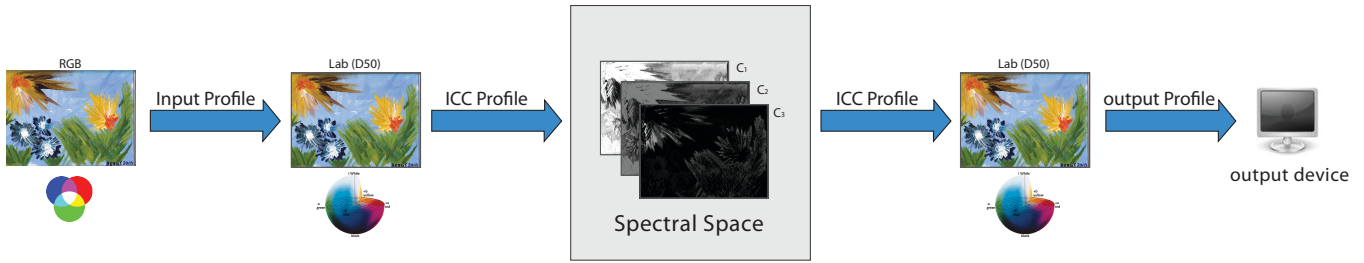


Figure 1. The workflow of converting a standard image to concentration space and the inverse process

## CIELAB to Concentration LUT

As shown in Figure 1, the first ICC profile converts CIELAB values to pigment concentrations. Pigment concentrations and CIELAB values cannot be converted using simple linear model, consequently, the ICC profile must be based on an LUT for conversions. In order to create the LUT to connect the concentration and CIELAB spaces, concentration of sets of pre defined CIELAB coordinates inside the ICC profile should be estimated using a subtractive mixing model. In this experiment, one-constant Kubelka-Munk model for opaque paints was used for concentration estimation. So,  $k/s$  values for each one of the pigments should be available in advance. The  $k/s$  values should not be essentially unit  $k/s$  values because absolute  $k/s$  curves can be changed based on colorant strength without affecting the final results. So,  $k/s$  curves were manipulated to get wider color gamut in this experiment. This is because many images are mapped to  $L^*$  between 0-100 and enhanced in chroma. In addition, since the pigments used in the painting and those chosen for this experiment might have different color strength, the concentrations can be related a scalar according to unit  $k/s$  for both pigment sets as an extra step.  $k/s$  curve were manipulated in two steps. At the first step, new unit  $k/s$  are determined so that they have the highest chroma in CIELAB space; in the way that, for each colorant, it assumed that available unit  $k/s$  value is a mixture of the colorant and white pigment. By varying, the concentration of assumed pigment in the mixture with white pigment, new  $k/s$  values with higher strength can be obtained. Among different calculated  $k/s$

values, the one with the highest chroma was chosen as corrected  $k/s$  values for each pigment. Afterward, a simple power function is applied on the  $k/s$  curve, which keeps the spectral shape of the  $K/S$  curves and increases the gamut of the pigments coincidentally. Figure 2 shows the  $k/s$  curves after correction. In this experiment, following acrylic dispersion paints were used: cadmium yellow medium, cobalt blue, quinacridone magenta, and titanium white. Due to limitation in the number of channels within an ICC profile, number of three chromatic pigments are selected in this experiment. The gamut of the colorants after and before manipulating the  $K/S$  values is shown in the Figure 3.

## LUT structure and gamut mapping

According to the structure of ICC profiles, the LUTs of the first space is always a predefined evenly divided space [8]. For example, in this study, a  $33 \times 33 \times 33$  gridding was defined in the CIELAB space with  $L^*$  ranging between 0 and 100 and  $a^*$  and  $b^*$  ranging between -128 and +127. In the concentration space, the corresponding concentration of the CIELAB values of the first table should be determined using a colorimetric match algorithm.

The concentration values were estimated by an iterative non-linear optimization method to minimize the CIEDE2000. Initial values for optimization algorithm were provided by a linear interpolation within another LUT. To build this LUT, the CIELAB values for  $20 \times 20 \times 20$  concentrations were calculated using one-constant Kubelka-Munk theory. Delaunay triangulation method together with linear interpolation method was used interpolation.

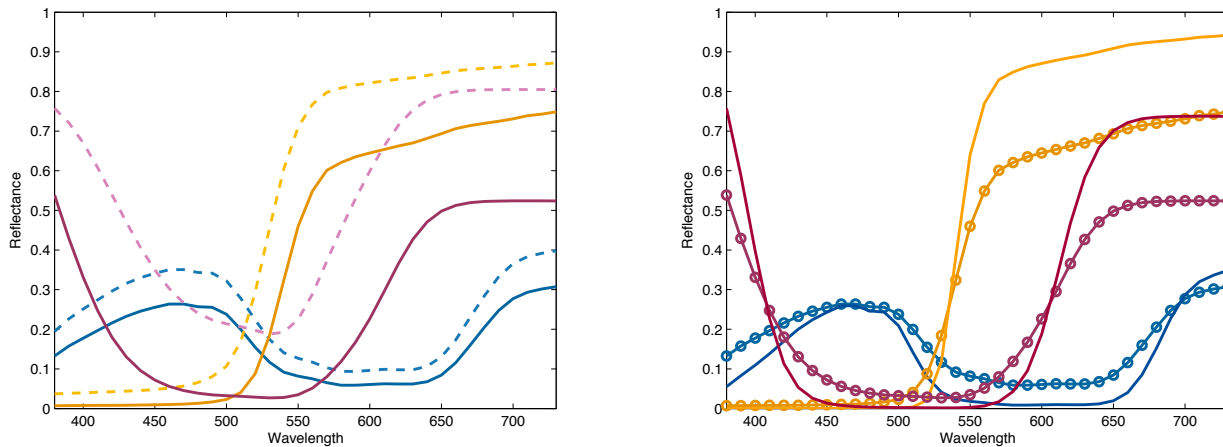
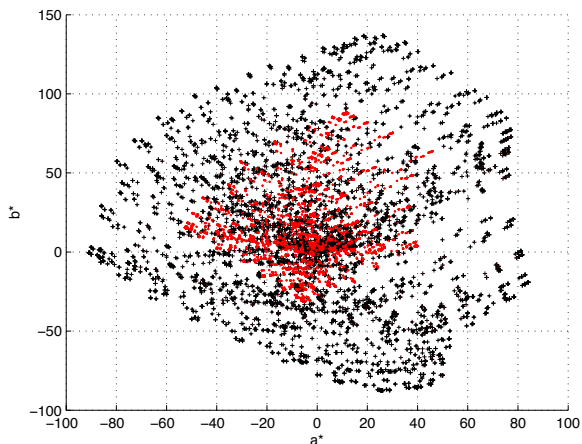


Figure 2. Reflectance curves of the colorants after and before correction. Left Plot: dashed lines are the measured reflectance curves, solid lines are reflectance curves with the most chroma in CIELAB space. Right Plot: circled lines are reflectance curves with the most chroma and solid lines are reflectance curves after applying power function.



**Figure 3.** The actual (red dots) and enlarged (black crosses) color gamut for chromatic primaries and white pigments.

Another advantage of using the initial values was to identify out of gamut points. Any point outside of the convex hull of concentration volume was marked as out of gamut point before optimization process. Out of gamut points were marked by assigning a color, for example gray, as used in Photoshop's gamut alarm feature. Another condition was applied for all optimized concentrations to be between one and zero and have CIEDE2000 values less than one.

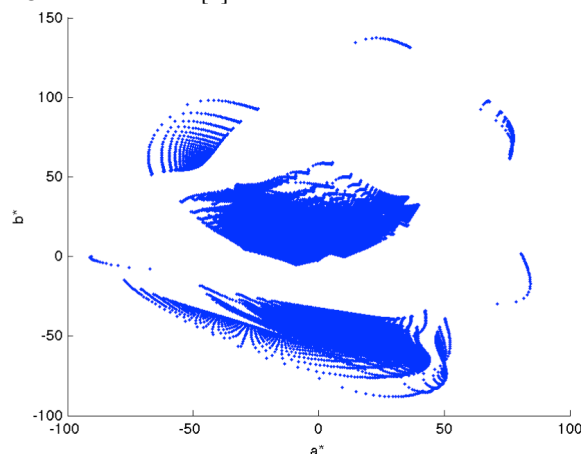
### Concentration to CIELAB LUT

In the inverse case, the estimated concentrations should be converted to colorimetric values. Accordingly, the first space in the LUT is concentration and destination space is colorimetric values for specific viewing condition. As far as Kubelka-Munk model estimates the reflectance properties form the concentration directly, the colorimetric coordinates are estimated without any optimization algorithm. However, because of non-linearity between concentration values and CIELAB values, the estimation of CIELAB using linear interpolation method, which is implemented inside the ICC profiles, can lead to large errors particularly for light colors. Figure 4 shows the CIELAB values calculated based on evenly gridded concentration values. As it is shown in the figure, there are not enough points available for some parts of the gamut.

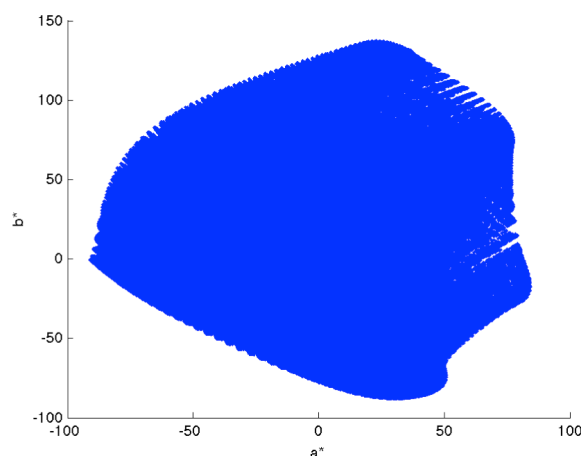
As an alternative, a non-linear function was applied on the concentration space compensating the nonlinearity issue. So, a gamma correction with the power of 2 is applied on the concentration data. The power of the gamma function depends on the characteristic of the colorants such as strength of the colorants. A better alternative is to use an LUT to relate the concentration to the scalars that have linear relationship with the colorimetric values. Figure 5 shows more linear space after applying the gamma correction on the data. It is seen that there are enough data available for all parts of the gamut with in the LUT.

The CIELAB values in the destination space are calculated based on the estimated spectral data. For example, in this experiment, the appearance of the image is estimated for Daylight (filtered tungsten with a CCT near D75) and Horizon light sources of GretagMacbeth SpectraLight III light booth. The spectral power

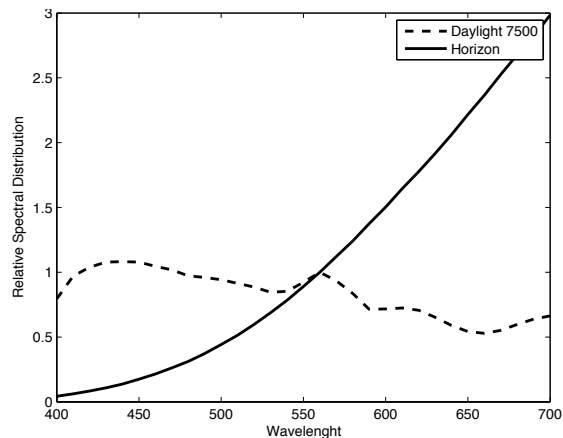
distributions of these light sources are shown in figure 6. A chromatic adaptation transformation is used to calculate corresponding colors from the test source to D50, the ICC PCS illuminant. For this research, the transformation within CIECAM02 was used [1].



**Figure 4.** Lab values calculated based on evenly gridded concentration.



**Figure 5.** CIELAB values calculated based on evenly gridded concentration after correcting for non-linearity



**Figure 6.** Relative spectral distribution of Horizon and Daylight light sources of GretagMacbeth SpectraLight III light booth.

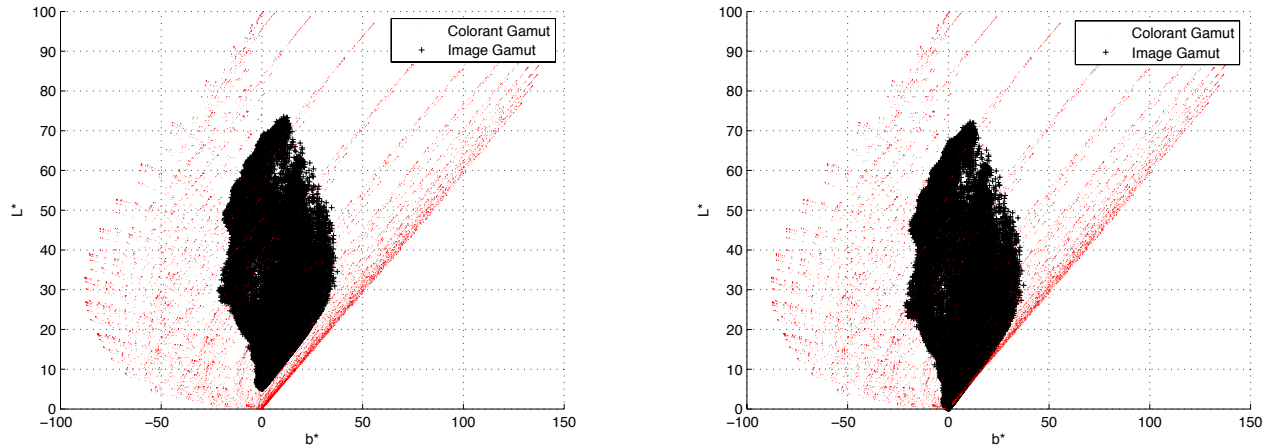


Figure 7. Color gamut of the painting after (Left) and before (Right) image compression.

### Luminance compression

Images of artwork are often mapped equivalent to media-related colorimetric rendering with black-point compensation. Even though the K/S values for the colorants were enhanced to achieve a larger color gamut, out-of-gamut limitations persist. Since the captured image might not be an absolute image, the image was compressed before entering the workflow. Figure 7 shows the color gamut of the test painting (displayed blow) after and before image compression.

However, there could be some out of gamut points because of the evenly gridding in the initial CIELAB space. The boundaries of the gamut cannot be specified precisely because CIELAB values are predefined to be evenly distributed in ICC profiles. Consequently, there would be some errors for colors near the boundary of the gamut in the interpolation procedure. Results can be improved by either applying gamut mapping algorithms or increasing the number of nodes at the first ICC LUT.

### The final workflow

Figure 8 shows the final workflow of using two ICC abstract profiles, which is the extended form of Figure 1. A CIELAB image is converted to concentration space and returns back to the destination CIELAB space with desirable viewing condition after adaptation. It is possible to manipulate the colorant concentrations separately in the concentration space as well.

### Experimental

The workflow was evaluated by using the Xrite ColorChecker Classic and SG with 24 and 140 samples, respectively. The reflectance data were measured using a SpectroEye spectrophotometer with 45:0 geometry. Colorimetric values of the color patches were calculated for 1931 standard observer for D50, Daylight and Horizon. The ICC profiles were applied on a test painting shown in Figure 9.

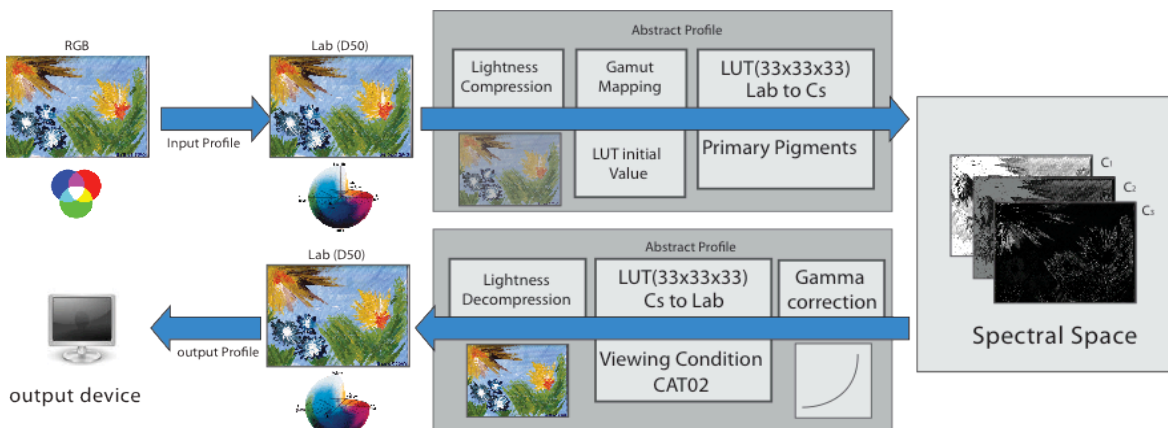


Figure 8. Final workflow using two ICC profile.





Figure 9. Color appearance of Flowers under D50 illuminant

## Results and Discussion

Two ICC profiles were created to simulate the changes in colorimetric values under Horizon and D75 light sources. Since D50 illuminant is the standard light source in ICC color management, CIELAB values under D50 were chosen as the source space for the first LUT. The output of the second LUT is CIELAB values under Horizon and D75 light sources adapted for illuminant D50. Colorimetric values calculated based on spectral data of the Color Checkers were compared with those estimated by the ICC profile. Table 1 shows color difference values for estimated and calculated data when no luminance compression is applied on the input data. In this table colorimetric values for Horizon and D75 light sources were calculated after adaptation for D50. The first row of the table shows the workflow in converting D50 to D50 illuminant to check the effect of interpolation on the data. The average DE2000 of 0.13 shows that the linear-interpolation process does not affect the results significantly. There were 2 and 23 out of gamut points for two color checkers. Color differences increase under Horizon and Daylight because the estimated and actual reflectance curves do not have same curvature, as the primary pigments were different. The larger color difference under Horizon illuminant shows difference in actual and estimated reflectance curves in longer wavelengths that can be because of choosing cobalt blue in the primary pigments. Figure 10 shows an estimated and actual reflectance for a gray color of Xrite Color Checker. Since a black pigment was not used to create the LUT, the estimated reflectance for a gray patch with flat reflectance is a metamer as shown in Figure 10.

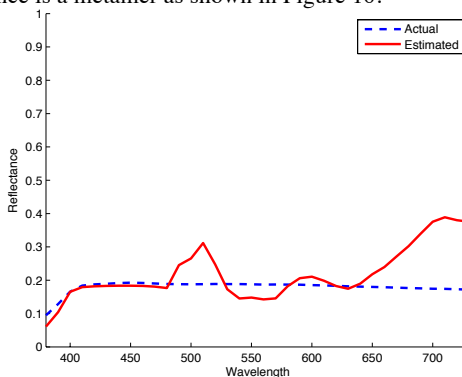


Figure 10. Estimated and actual reflectances for a gray sample of ColorChecker Classic.

**Table 1: Color difference values for colorimetric values estimated by ICC profile and colorimetric values calculated using reflectance data. No luminance compression is applied.**

	Xrite ColorChecker Classic			
	DE2000			
	Mean	Variance	Max	Out of Gamut
D50	0.13	0.36	2.80	2
Horizon	3.37	7.84	10.38	2
D75	0.96	0.62	3.06	2

	SG Color Checker			
	DE2000			
	Mean	Variance	Max	Out of Gamut
D50	0.07	0.19	3.83	23
Horizon	3.99	11.09	10.74	23
D75	1.19	0.87	3.98	23

Table 2 show color difference values after applying luminance compression. There is no out of gamut colors for the Classic and only two out of gamut color for the SG. The Color difference for D50 to D50 conversion was improved, as image gamut is smaller than the pigments gamut. However, color difference values don't change significantly for other light sources.

**Table 2: Color difference values for colorimetric values estimated by ICC profile and colorimetric values calculated using reflectance data after applying luminance compression.**

	Xrite ColorChecker Classic			
	DE2000			
	Mean	Variance	Max	Out of Gamut
D50	0.00	0.00	0.02	0
Horizon	3.56	5.29	9.60	0
D75	1.05	0.32	2.80	0

	SG Color Checker			
	DE2000			
	Mean	Variance	Max	Out of Gamut
D50	0.01	0.02	1.46	2
Horizon	3.83	5.49	11.23	2
D75	1.08	0.41	3.26	2

Figures 11 shows an example of an image under different light sources using these ICC profiles. Photoshop's "convert to profile" was used to apply the calculated profiles on the images. As shown in the figure, the blue background becomes slightly reddish under Horizon illuminant. This shift was because cobalt blue was one of the pigments used in the database. If the primary pigments

are selected correctly, the appearance of the painting can be simulated using this method.



**Figure 11.** Color appearance of Flowers for each listed illuminant. Original image under D50 illuminant (top), Horizon light source (Middle), D75 light source (Bottom).

## Conclusion

In this research, ICC profiles were used to calculate the concentration of certain pigments and reproduce the image in different viewing conditions. Two abstract profiles were used to convert the CIELAB values of the image into concentration space and return concentrations to the CIELAB. Two main issues were discussed in the color conversion. First is the non-linearity between

the concentration and colorimetric values. The non-linearity can be the source of error in linear interpolation and distribution of points in the second LUT. An iterative optimization loop in first LUT and gamma correction in the second LUT were used to solve non-linearity problem. Second is out of gamut colors. In order to prevent out of gamut colors, the colorant K/S values were corrected to obtain larger gamut by the colorants. The image was also compressed before entering the workflow. The result of the first LUT is the estimation of concentrations as an image. This space can be considered as a spectral space since spectral information can be extracted using concentration values for each pixel. Based on the spectral reflectance of each pixel, the colorimetric values of the image were estimated using second ICC profile. Therefore, the image can be viewed under different viewing conditions. There are some limitations in using ICC profile for color conversion; however, using ICC profiles are simple and fast. ICC profiles are helpful in different imaging industries such as printing industry or museum community to see the appearance of the artworks in alternative viewing conditions.

## References

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