Migration of Photo CD Image Files

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Abstract

Kodak's Photo CD system, originally intended for consumer applications, has been used successfully by museums and libraries to store digital images from scanned film, prints and documents. With recent advances in digital image standards and their anticipated adoption by cultural institutions, questions arise as to how best to convert Photo CD image files. We describe both the file format and colorimetric definition of image data stored on a Photo CD disc. Particular attention is paid to retaining the full range of encoded subject luminance values, and compatibility with methods for exchange and display of digital images. The requirements for migration are discussed in terms of retention of subject color information. From this it is possible to evaluate various options for digital migration.

Introduction

The permanence of digital collections for cultural and preservation institutions will depend upon the development of digital conversion strategies. These will include methods for digital image migration that not only retain current image integrity, but also allow for technology improvements. Most Photo CD image files[1] were derived from the scanning of photographic film. These disks are known as Photo CD Master and PRO Photo CD discs, and they are the topic of this paper. In this case the image data provides a colorimetric description of the original subject matter. For files not derived from scanned photographic film, such as Portfolio Photo CD disks, the colorimetric interpretation may not be as well defined. For both types of Photo CD image files, the adopted digital migration strategy will depend on the objectives of the cultural institution and likely future uses.

We consider several criteria for digital image migration that might be adopted by cultural institutions. Our primary focus will be on preserving the image information for future use. The specific file format chosen, e.g. JPEG 2000,[2] will not be addressed. Before considering the likely technical requirements for the library and museum communities, we address several important aspects of the Photo CD system and image encoding.

Kodak's Photo CD System

The Photo CD system includes a unique image color-encoding specification and image file format to support a disparate assortment of input imaging media and devices and both hardcopy and softcopy outputs. The color-encoding specification also conforms closely to industry standards for imaging devices that produce output video signals in order for Photo CD discs to produce high quality images on existing video systems without requiring custom display adjustments.

The Photo CD Image Pac file format[3] supports multiple image-display resolutions, ranging from those for typical softcopy displays up to photographic-quality hardcopy resolutions. It employs a hierarchical image-storage scheme aimed at balancing the degree of data compression and retention of visible image detail, and it enables an efficient means to decompress and display images.

These and other features of the Photo CD system, and the fact that Kodak designed the system to maintain the integrity of the image color-encoding specification and file format, made it a viable choice for cultural and preservation institutions to photograph, digitize, and archive their collections.

PhotoYCC Color-Encoding Specification

The PhotoYCC color-encoding specification[4,5] developed to meet the system's unique objectives is based on the colorimetry of the original subjects (usually illuminated objects) that caused the image to form on the input imaging medium being scanned. The original-subject colorimetry is encoded in terms of RGB exposure-factor values, which would have been produced by a theoretically defined reference image-capturing device, had it captured the same original subject, illuminated by CIE Standard Illuminant D_{65}. The RGB exposure-factor values are derived by applying appropriate input signal-processing transformations to the RGB values scanned from input media. The chromaticity of CIE Standard Illuminant D_{65} is used as a white reference in these transformations; however, the use of other subject illuminants can be accommodated by the additional inclusion of chromatic adaptation transformations.

To achieve the Photo CD system color-gamut objectives, the defined red, green, and blue spectral responsivities of the reference image-capturing device are equivalent to the color-matching functions for the red, green, and blue reference primaries specified for ITU Recommendation ITU-R BT.709, *The HDTV Standard for the Studio and for International Programme Exchange*. All-positive RGB exposure-factor values of the reference image-capturing device are equivalent to signal values of actual video cameras conforming to the Rec. 709 specifications. However, because it is defined as a mathematical reference for the encoding specification, the reference image-capturing device also can form negative RGB exposure-factor values, making it possible to represent colors outside the displayable color gamut of a video system. The *PhotoYCC* color-encoding specification accommodates a range of original subject colors typically encountered in most imaging situations that goes beyond the range of the video system reference primaries*. This is illustrated the CIE *u', v'* chromaticity diagram of Fig. 1.

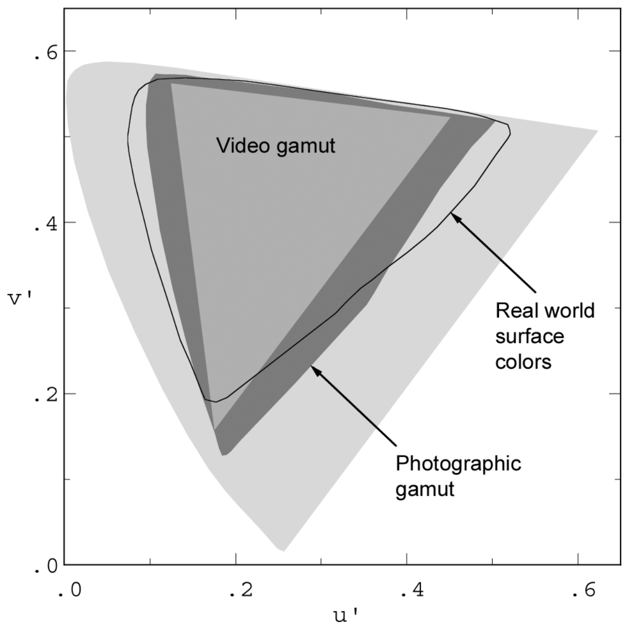

Figure 1: Comparison of video, photographic and real-world color gamuts in CIE u', v' chromaticity coordinates.

The *PhotoYCC* color-encoding specification also deals with the extensive range of luminances contained in most original subject matter and captured by input photographic media, including specular highlights, certain types of diffuse highlights, and subject matter areas more highly illuminated than the principal subject area. The histogram of Figure 2 shows the dynamic range of luminance-factor values of an original photographed subject. The shaded area indicates subject information corresponding to luminance-factor values above those of perfect diffuse whites in the principal subject area. Because the reference image-capturing device is hypothetical, it is specified to produce a correspondingly extensive dynamic range of RGB exposure-factor values. Luminance-factor values up to two times that produced by a perfect white in the principal area of an original subject are accommodated by the *PhotoYCC* color-encoding specification.

Visibility of quantization artifacts and colorimetric digitization errors are minimized in the *PhotoYCC* color-encoding specification by specifying nonlinear transformations to the reference image-capturing device linear RGB exposure-factor signals prior to digitization. The nonlinear transformation employed corresponds closely to the opto-electronic transfer characteristic specified in ITU Rec. 709, which simplifies output signal processing for producing video signals from Photo CD discs. The *PhotoYCC* color-encoding specification's nonlinear transform definition also accounts for reference image-capturing device RGB exposure-factor values that are negative or that correspond to beyond-white luminance information to preserve the color gamut and luminance dynamic range inherent in original subject matter.

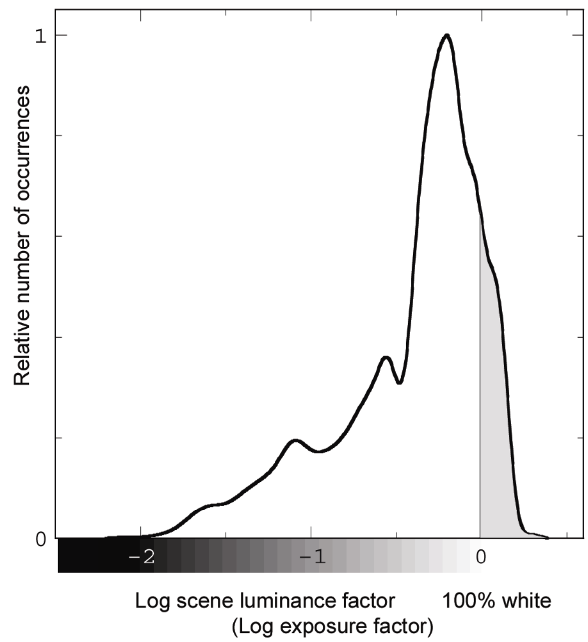

Figure 2: The extended luminance range

The Photo CD system employs an image compression process that includes chroma subsampling. In this technique, red, green, and blue image signals are converted to an achromatic channel and two color-difference channels. The achromatic information is stored at full image resolution, while color-difference information is stored at a lower resolution. Because of the nature of the human visual system, images produced from full-spatial-resolution achromatic information and lower-spatial-resolution color-difference information generally are perceived to have the visual quality of full-spatial-resolution RGB color images.

To provide for this compression, the *PhotoYCC* color-encoding specification includes a transformation of nonlinear RGB signals to achromatic and color-difference signals. This transformation is derived from the NTSC color primaries to ensure compatibility with most video-signal encoder and decoder circuits as well as most video-based software, thus simplifying conversion to standard output video signals.

The final step in the encoding process is the conversion of the achromatic and color-difference signals to 8-bit digital code values. The transformation equations used in this process allow virtually all surface colors, including those found in nature and those produced from manufactured colorants, to be encoded.

The practical range of luminance-factor values that can be encoded using the *PhotoYCC* color-encoding specification

*Figs. 1–3 are reproduced from *Digital Color Management: Encoding Solutions,* E. J. Giorgianni & T. E. Madden, ©1998 Eastman Kodak Company extends from 0.0057 to 2.00, i.e., to twice the luminance factor of a perfect white. The total dynamic range therefore corresponds to an approximately 350:1 ratio of luminances, or a log luminance-factor range of about 2.5. This is sufficient to retain the extensive dynamic range of luminance information that can be recorded by most photographic media.

Image Decomposition

The Photo CD Image Workstation scans 35 mm input images at a resolution of 2048 lines × 3072 pixels in each of three colors (RGB). This results in 18 MB of full-color data per image, roughly comparable to capture by a single-chip 8-9 megapixel digital camera. Resolutions of up to 4096 × 6144 × 3-colors also are possible for larger-format film inputs using the *Kodak* PCD Scanner and Pro Photo CD discs. The Photo CD system incorporates hierarchical image decimation and interpolation to compress image data while minimizing visible loss of detail and enabling efficient reconstruction of output images at various display resolutions.

As described earlier, The *PhotoYCC* color-encoding specification includes a transformation from RGB signals to luminance and color-difference signals. This permits compression of the image data by subsampling and storing of the achromatic channels to resolutions lower than that at which the luminance channel is stored.

Residual image files, representing the differences in image detail between successive image resolutions, are created and are used for reconstructing output images with visually undetectable loss in image detail. An output image is reconstructed by interpolating a stored compressed image up to a desired output resolution and the corresponding-resolution residual image is added, restoring the image detail lost in the decimation/interpolation process. The statistics of image residuals lend themselves well to Huffman encoding for further overall data compression. This strategy produces a non-redundant hierarchy of images that is efficient for both display and storage.

Format and File Structure

An image is stored on a Photo CD disc in an Image Pac, which is a collection of various-resolution image components and corresponding residuals, as well as associated metadata.
Image Pac files are stored on a Photo CD disc according to the arrangement shown in Table 1.

Table 1:Photo CD Image Pac Sampling

Image Pac Component	Luma resolution	C1 resolution	C2 resolution
Base/16	128 × 192	64 × 96	64 × 96
Base/4	256 × 384	128 × 192	128 × 192
Base	512 × 768	256 × 384	256 × 384
4Base	1024 × 1536 residual		
16Base	2048 × 3072 residual	1024 × 1536 residual	1024 × 1536 residual

This structure meets the goals of straightforward image access and high image quality with the lower-resolution image components stored in uncompressed form, which are easily decoded into standard video signals. The compression rates achieved are relatively modest: The 18 MB of an original 2k × 3k × 3-color scanned image is reduced to approximately 4.5 MB. This permits storage of 100 images per Photo CD disc, while ensuring the photographic quality of the original input image is preserved and is digitally accessible in an efficient manner.

Photo CD Image File Migration

It is just over a decade since Kodak introduced the Photo CD system, its unique *PhotoYCC* color-encoding specification, and the multi-resolution Image Pac file format. Many cultural heritage and preservation institutions worldwide created, and still possess, collection archives on Photo CD discs, some numbering into the hundreds-of-thousands of images.

In the intervening years, the world-wide web has had unprecedented impact as a means for disseminating information, and with it has come the rapid development and acceptance of digital imaging, including new image file formats and software protocols for handling image files. Cultural institutions having interest in using these new technologies to make collections widely available should consider potential tradeoffs in converting from an image encoding system well suited to the requirements for cultural preservation to these newer formats.

Considerations for Migration

Because the *PhotoYCC* color-encoding specification is colorimetrically defined, many options for conversions to other color-encoding metrics and image file formats are possible. Consideration should be given as to whether the inherent features of *PhotoYCC*-encoded images should be retained, modified, or possibly lost. Specifically, the importance of several image attributes should be taken into account.

Original-subject nature of Photo CD-encoded image colorimetry

Photo CD technology was often chosen for cultural preservation image archiving because its images are encoded in terms of the colorimetry of the original subject matter, not the colors as reproduced on the input imaging media. This is particularly important for archiving the objects contained in collections. Selection of an appropriate color-encoding specification for migration of Photo CD-archived collection images should retain the salient nature of the original-subject colorimetry. Conversions of Photo CD images to many current and popular image file color-encoding metrics can result in serious and irretrievable loss of original color information.

Color-gamut and luminance dynamic range of importance

The Photo CD system's extensive gamut of encodable colors also is well suited to cultural object image archiving. The *PhotoYCC* color-encoding specification is designed to unambiguously encode colors created using pigments and other materials that can go beyond the chromaticity range of softcopy output devices. Again, the selection of an appropriate color-encoding specification for migration should preserve this color information to maintain integrity of the archive. Likewise, *PhotoYCC's* extended luminance dynamic range preserves luminance-factor values in original subjects beyond those of a diffuse white in the principle area of the image. This can be particularly important for preserving the appearance of three-dimensional objects presented with preferential lighting displays that can produce specular and diffuse highlights.

Preliminary PhotoYCC data-metric conversion for migration

When appropriate image-data conversion procedures are employed, such as those described here, migration of *PhotoYCC* color values to other suitable color-encoding specifications can be accomplished in an unrestricted fashion. The first step in any such migration is a data-metric conversion of *PhotoYCC Y*, C_1, and C_2 digital color values into original-subject CIE *XYZ* tristimulus. A data-metric conversion for generating original-subject tristimulus values is provided as a basis for subsequent migration to suitable color-encoding specifications and file formats that retain the Photo CD inherent image-encoding features.

PhotoYCC to original-subject CIE XYZ tristimulus values data-metric conversion steps

In the first step of the data-metric conversion, luma and chroma values are computed from *PhotoYCC Y*, C_1, and C_2 digital color values. For 24-bit (8-bits per color channel) encoding, luma and chroma values are computed according to the following equations:

$$Luma = \frac{1.402}{255} Y$$

$$Chroma_1 = \frac{(C_1 - 156)}{114.40} \qquad (1)$$

$$Chroma_2 = \frac{(C_2 - 137)}{135.64}$$

The resulting *Luma*, $Chroma_1$, and $Chroma_2$ values are converted to nonlinear values, $R'G'B'_{709}$, using the following matrix transformation,

$$\begin{bmatrix} R'_{709} \\ G'_{709} \\ B'_{709} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1 \\ 1 & -0.194 & -0.509 \\ 1 & 1 & 0 \end{bmatrix} \begin{bmatrix} Luma \\ Chroma_1 \\ Chroma_2 \end{bmatrix}. \qquad (2)$$

The $R'G'B'_{709}$ nonlinear values are converted to linear exposure-factor values, RGB_{709}, using the following equations. For $R'G'B'_{709} \geq 0.081$,

$$R_{709} = \left(\frac{R'_{709} + 0.099}{1.099} \right)^{1/0.45}$$

$$G_{709} = \left(\frac{G'_{709} + 0.099}{1.099} \right)^{1/0.45} \qquad (3)$$

$$B_{709} = \left(\frac{B'_{709} + 0.099}{1.099} \right)^{1/0.45}.$$

For $R'G'B'_{709} \leq -0.081$,

$$R_{709} = -\left(\frac{R'_{709} - 0.099}{-1.099} \right)^{1/0.45}$$

$$G_{709} = -\left(\frac{G'_{709} - 0.099}{-1.099} \right)^{1/0.45} \qquad (4)$$

$$B_{709} = -\left(\frac{B'_{709} - 0.099}{-1.099} \right)^{1/0.45}.$$

For $-0.081 < R'G'B'_{709} < 0.081$,

$$R_{709} = \frac{R'_{709}}{4.5}$$

$$G_{709} = \frac{G'_{709}}{4.5} \qquad (5)$$

$$B_{709} = \frac{B'_{709}}{4.5}.$$

The RGB_{709} exposure-factor values are then converted to CIE $XYZ_{D_{65}}$ values using the following matrix transformation,

$$\begin{bmatrix} X_{D_{65}} \\ Y_{D_{65}} \\ Z_{D_{65}} \end{bmatrix} = \begin{bmatrix} 41.24 & 35.76 & 18.05 \\ 21.26 & 71.52 & 7.22 \\ 1.93 & 11.92 & 95.05 \end{bmatrix} \begin{bmatrix} R_{709} \\ G_{709} \\ B_{709} \end{bmatrix} \qquad (6)$$

Table 2 shows the results of using the data-metric conversion procedure outlined above, to convert several reference neutral *PhotoYCC Y*, C_1, and C_2 values to CIE *XYZ* tristimulus values.

As can be seen from Table 2, the extended luminance dynamic range of the PhotoYCC color-encoding specification results in a correspondingly extensive range of CIE *XYZ* tristimulus values that must be preserved in subsequent migration transformations to retain full Photo CD image quality. These migrations will be the topic of a second article.

Table 2: CIE XYZ values converted from PhotoYCC values

Reflectance	Y	C_1	C_2	X	Y	Z
0.57% black	5	156	137	0.58	0.61	0.67
20% gray	79	156	137	19.01	20	21.78
100% white	182	156	137	95.05	100	108.90
200% highlight	255	156	137	190.10	200	217.80

Metadata Migration

Since the propagation of data used for image indexing and retrieval is a large part of any migration project, it useful to address two types of data available. Consider the draft NISO standard[6] for technical image metadata. Several of the NISO elements, such as scanner model and software, are stored as part of each Photo CD file. The table in the Appendix lists these.

Following the above discussion of the system, we can populate several additional elements. The additional data are inferred from the color encoding used in the images files and represent an opportunity to improve future collections. It is worthwhile emphasizing that these elements are specific to Photo CD images. If conversion to other color spaces or sampling resolutions occurs at migration, the appropriate elements should reflect those changes.

Conclusions

For conversion of Photo CD master files, where the retention of image information is a priority, consideration should be given to the several attributes of the currently stored color-image information. The legacy color encoding provides this link, and in many cases the original-subject colorimetry will be important. For example, the retention of an extended luminance range will likely be important for collections with outdoor subjects, metallic materials or glassware, or objects composed of colorants that fluoresce. If original subject information is preserved, derivative file versions for specific uses and distribution then can be generated as needed.

Several file format options are currently available, and this choice often can be made independently of the choice of migration color encoding. Here the choice likely will be influenced by considerations such as the availability and adoption of standards, metadata support and quality of file compression.

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Appendix: NISO Z39.87 Metadata Elements

NISO Z39.87 (draft) element	PCD header items	Additional items defined by PCD system
7.6.1.1 ScannerManufacturer	✓	
7.6.1.2.1 ScannerModelName	✓	
7.6.1.2.2 ScannerModelNumber	✓	
7.6.1.2.3 ScannerModelSerialNo	✓	
7.6.2.1 ScanningSoftware	✓	
7.6.2.2 ScanningSoftwareVersionNo	✓	
7.6.3.1 PixelSize		✓
7.6.3.2.1 XphysScanResolution		✓
7.6.3.2.2 YphysScanResolution		✓
8.2.5 GrayResponseCurve		✓
8.2.6 GrayResponseUnit		✓
8.2.7.1 WhitePoint Xvalue*		✓
8.2.7.2 WhitePoint Yvalue*		✓
8.2.8.1 PrimaryChromaticities RedX*		✓
8.2.8.2 PrimaryChromaticities RedY*		✓
8.2.8.3 PrimaryChromaticities GreenX*		✓
8.2.8.4 PrimaryChromaticities GreenY*		✓
8.2.8.5 PrimaryChromaticities BlueX*		✓
8.2.8.6 PrimaryChromaticities BlueY*		✓

*Note that the CIE chromaticity values, denoted as X and Y in the NISO standard, are written as x and y in the color-science and imaging communities.