Introduction to Color Facsimile: Hardware, Software and Standards

Daniel T. Lee
Hewlett-Packard Laboratories
1501 Page Mill Road, Palo Alto, California 94304, USA
Internet: dlee@hpl.hp.com

Abstract

The design of a color facsimile machine presents a number of unique challenges. From the technical side it requires a very efficient, seamless integration of algorithms and architectures in image scanning, compression, color processing, communications and printing. From the standardization side, it requires that agreements on the color representation space, negotiation protocols and coding methods must be reached through formal international standardization process. This paper presents an introduction to the overall development of color facsimile. An overview of the recent development of the international (ITU) Color Facsimile Standard is first presented. The standard enables the transmission of continuous-tone colors and gray-scale images in Group 3 (over conventional telephone lines) and Group 4 (over digital lines) facsimile services, with backwards compatibility to current black and white facsimile. The standard provides specifications on color representation and color image encoding methods as well as extensions to current facsimile protocols to enable the transmission of color images. The technical challenges in implementing the color facsimile standard on existing facsimile machines are described next. The integration of algorithms and architectures in color scanning, compression, color processing, transmission and rendering of received hardcopy facsimile in a color imaging pipeline is described. Lastly, the current status on soft-copy color facsimile standardization is reported.

Keywords: Facsimile, color facsimile, image compression, image transmission, ITU, CCITT, JPEG, CIELAB, color space

1. Introduction

This paper presents an introduction to the overall development of color facsimile. It gives an overview of the standardization process for color facsimile over the last several years and describes some of the challenges in the implementation of the new standard. Research and development of color facsimile can be dated prior to 1940's. This effort has resulted in expensive and proprietary systems for special applications, such as the transmission of color photographs by news delivery services. Three breakthroughs have occurred that will soon make color facsimile as ubiquitous as plain paper facsimile is now:

1. *Digital Imaging*. New image compression algorithms allow considerable reduction of the image data size that makes it viable to transmit images over the public-switched telephone network (PSTN) using conventional modems.
2. *Hardware Cost*. The cost of high performance processors, color scanners, and color printers have come down considerably. Color facsimile machines can now be de signed with a target price affordable to departmental work groups or even home users.
3. *International Standard*. The International Telecommunication Union—Telecommunication Standardization Sector (ITU-T) approved new color facsimile standard in November 1994. This means that users can universally exchange color images with remote users independent of the manufacturer or type of the facsimile machines used as long as they are compliant with the ITU standard.

This paper is organized as follows. In Section 2, an overview of the recent development of the first international ITU Color Facsimile Standard is presented. In Section 3, the technical challenges in implementing the color facsimile standard are described. In Section 4, the work on soft-copy to color facsimile standard is reported. Lastly, the problems and prospects for color management in the context of color facsimile are explored.

2. Development of Color Facsimile Standards[1,2]

2.1 Background

The patent on the first facsimile machine was issued to Alexander Bain in 1843[3] and the first commercial use of facsimile service was introduced in 1865 between Paris and Lyon. Transmission of color images using analog signals over wire was reported by Bell Laboratories in 1925.[4] Although niche markets such as newspaper companies and news delivery services have provided services to transmit color image since the 1940's, widespread use of color image transmission was limited. There was neither any effective input/output system for color images nor any standardized encoding method for continuous-tone images. Two major developments in the 1980's—the standardization of digital facsimile standard and the development of image coding standard, paved the way for the development of color facsimile in the 1990's.

The standardization of image formats and transmission means for facsimile is developed under the auspices of the ITU (formerly the CCITT). This body consists of representatives from member countries and delegates from companies, agencies and countries. Telecommunications standards developed within the ITU are approved by member countries and published by the ITU called Recommendations for implementation worldwide. The facsimile communications standards are among the most successful and widely used of these standards. The Group 3 facsimile standard, a digital protocol designed to operate over analog data channels, was formally approved in 1981. It has become the most widely used of the two standards and is used throughout the world over general switched telephone networks. The Group 4 standard, designed to operate over digital channels, is implemented in a more limited set of regions. Recent extensions of the Group 3 standard also allows the use of this protocol over digital channels.

In image coding field, efforts to standardize the encoding of images, both continuous-tone and bi-level images began in 1986 under the joint auspices of ISO/IEC and the ITU. In 1992, after many years of committee work, two standards were approved—the JPEG (Joint Photographic Experts Group)[5] and the JBIG (Joint Bi-level Image Experts Group).[6] With this background, ITU-T commenced its standardization activity of color facsimile in 1990.

Committee work on the color facsimile started at the CCITT SG VIII Budapest meeting in March 1990. A study proposal on business color images was introduced by Nippon Telegraph and Telephone Company of Japan. In that proposal, business color images were classified into the following four document types:

- full color : color photographs,
- multi-color : color charts and graphs,
- bi-color : documents marked by red ink,
- mixed color : combination of above documents, such as color pages of magazines.

The work would also proceed in two steps:

- first step : JPEG (for continuous-tone images),
- second step : JBIG, soft-copy with progressive build-up and mixed color.

2.2 Device-Independence Color Space

An important subject in the development of color facsimile standard was the selection of an interchange color space, a device-independent space for color representation. This effort was the subject of intense study and discussion during 1992 and 1993. The work proceeded along the following steps:

1) determine color space candidates,
2) determine the evaluation criteria,
3) determine the evaluation methods,
4) determine the weight for each evaluation criterion,
5) obtain total score and select color space.

In order for the selection to be inclusive of many candidates, the following color spaces were taken in consideration:

- XYZ,
- CIELAB,
- CIELUV,
- CMYK,
- CES RGB,
- YIQ (linear),
- YC_bC_r (linear),
- HSL/HSV/HSI,
- CIELAB Polar Coordinate,
- CIELUV Polar Coordinate,
- NTSC RGB,
- RGB Density,
- YIQ (gamma),
- YC_bC_r (gamma),
- Munsell Renotation System.

The committee then established the following ten evaluation criteria:

- device independence,
- quantization error,
- compatibility with compression algorithms,
- ability to represent all visible colors,
- color stability with white point change,
- transformation from/to XYX,
- transformation from/to input device color space,
- transformation to output device color space,
- compatibility with black and white data,
- compatibility with the other standards and instruments.

Weighted scores for each evaluation criterion were determined for each color space candidate. The Japanese delegation in particular performed an exhaustive study on the evaluation. The result of the committee work was that CIE (1976) L*a*b* space (CIELAB) was chosen as a flexible, relatively uniform, and device-independent color specification. This result was in agreement with published work in the United States.[5]

2.2.1 Illuminant and White Point. Since CIELAB is a relative color metric, the choice of illuminant, white point, and measurement conditions is necessary to define the representation precisely. The CIE D50 illuminant and its perfectly diffuse reflecting white point (X_0 = 96.422, Y_0 = 100.000, Z_0 = 82.521) were chosen as the basic illuminant and white point respectively in agreement with common practice in the graphic arts industry. A measurement geometry of 45-0 degree illuminant to measurement angle is also specified. These measurement conditions are defined as an ISO standard for graphic arts measurement.[7]

2.2.2 Gamut Range. The default gamut range chosen is as follows:

$$L^* = [0, 100],$$
$$a^* = [-85, 85],$$
$$b^* = [-75, 125].$$

It was chosen to serve several goals. The default gamut range is sufficiently wide to span existing hard copy output devices. The range is narrow enough to avoid excessive quantization error when the data is represented in eight bits/component.[8] The particular choices of gamut range are believed to represent existing hard copy devices, as well as facilitating effective implementation.

The digital representation of the image data was next determined. The conversions from real values in CIELAB to the eight-bit integer representations are performed as show:

$$L = (L^*) * (255/100),$$
$$a = (a^*) * (255/170) + 128,$$
$$b = (b^*) * (255/200) + 96,$$

where L, a, and b represent eight bit integers, and L*, a*, and b* represent real numbers.

Following successful negotiation in the facsimile protocol, any alternative gamut range may be specified by the transmitter. This is intended to allow for soft-copy device gamuts or for more accurate specification of colors within a narrower gamut range. In addition, 12 bits/channel of data may be transmitted as an option.

The above results were captured in a new ITU standard formally approved in 1995, called the ITU-T T.42 - Continuous-tone Colour Representation Method for Facsimile.[10]

2.3 Common JPEG Data Structure

Next, the encoding of the color image data is determined. A common JPEG data structure based on the baseline JPEG standard,[5] that is, sequential DCT (Discrete Cosine Transform) and Huffman encoder, is used for Group 3 and Group 4 color facsimile. The encoded image data consist of a series of markers, parameters, and scan data that specific the image coding parameters, image size, bit-resolution, and entropy-encoded block-interleaved data. The JPEG data structure for color facsimile application has the following elements: parameters, markers, and entropy-encoded data segments. Parameters and markers are often organized into marker segments. The markers used in the color facsimile application are characterized as follows:

(1) The encoder shall insert there markers, and the decoder shall able to carry out a corresponding process upon these marker segments:

```
SOI, APP1, DQT, DHT, SOF0, SOS, EOI.
```

(2) The encoder may insert these markers without negotiation, and the decoder shall be able to carry out a corresponding process upon these marker segments:

```
DRI, RSTn, DNL.
```

(3) The encoder may insert this marker without negotiation, and the decoder shall skip these marker segments and continue the decoding process:

```
COM, APPn (n not 1).
```

(4) The encoder may insert this marker when the decoder has the ability to carry out a process corresponding to this marker segment (negotiation is necessary). If used, it replaces SOF0 in the data stream:

```
SOFn (n not 0).
```

The APPn markers are undefined markers provided in JPEG to facilitate the adaptation of the standard to particular applications. In establishing the standard for color facsimile, the APP1 marker is reserved and defined for the exclusive use for color facsimile applications. In particular, the APP1 initiates identification of the image as a G3FAX or G4FAX application, and defines the spatial resolution and subsampling. The marker directly follows the SOI marker and has the following format:

```
X'FFE1' (APP1), length, FAX identifier,
version, spatial resolution.
```

The spatial resolution chosen as basic for color facsimile is 200 × 200 pels/25.4 mm. This spatial resolution is familiar in most fax machines as the "fine mode." In addition, two optional identifiers are used to describe the gamut range and illuminant data that are used, respectively.

Inside the scan data structure, the scan data consist of block interleaved L*, a*, and b* data. Blocks are entropy-encoded DCT-transformed 8 × 8 arrays of image data from a single image component. When a gray-scale image is transmitted, only the L* component is represented in the data structure. The number of image components is either one (for a gray-scale image) or three (for a color image).

The data are block-interleaved when a color image is transmitted, and only one scan is contained within the image data. The blocks are organized in minimum coding units (MCU) such that an MCU contains a minimum integral number of all image components. The interleaving has the following form in the default (4:1:1) subsampling case. In this case an MCU consists of four blocks of L* data, one block of a* data, and one block of b* data. The four L* blocks proceed in the same scan order as the page: left to right and top to bottom. The default (4:1:1) subsampling is specified as four coefficients (tap) filter with coefficients (1/4, 1/4, 1/4, 1/4). Thus a* and b* are computed from non-subsampled data by averaging the four values of chrominance at the lightness locations (Fig. 1).

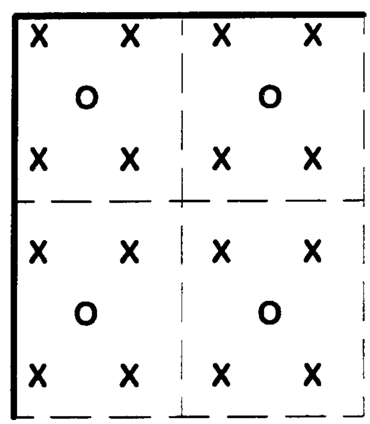

Figure 1. Positions of pels centers following chroma subsampling. X represents lightness pel centers, and O represents chroma pel centers.

The subsampling reduces the number of DCT calculations needed for image coding, and takes advantage of the lower visual sensitivity opt chroma modulation. In addition, optional spatial resolution of 300 × 300 and 400 × 400 pels/25.4 mm are available upon successful negotiations, as is a non-subsampled chroma mode.

2.4 Structure of Group 3 Color Facsimile Recommendation

The protocol for Group 3 facsimile is governed by the ITU-T Recommendation T.30,[11] commonly known as the

G3 protocol. A successful G3 facsimile transmission session can be generally divided into five parts:

(1) *Phase A - Call Setup.*
(Calling tone and called station identification.)

(2) *Phase B - Pre-message Procedure.*
(Exchange of signals to identify capabilities of calling unit and called unit with the use of *DIS* - Digital Identification Signal, *DCS* -Digital Command Signal, and *DTC* - Digital Transmit Command.) (Training signals and confirmation to receive.)

(3) *Phase C - Fax Message Transmission.*
(Transmit encoded data and return to control.)

(4) *Phase D - Post-message Procedure.*
(End of procedure, multi-page signal and message confirmation signal.)

(5) *Phase E - Call Release.*
(Disconnect.)

In Group 3 Color Facsimile, the negotiation to transmit and receive JPEG encoded continuous-tone color and gray- scale image is invoked through the setting of the bits in the DIS/DTC and DCS frames during the pre-message procedure (Phase B) of the protocol.

Mandatory	Optional
8 bits/pel/component	12 bits/pel/component
4:1:1 subsampling	No subsampling (1:1:1)
CIE D50 Standard Illuminant	Custom illuminant
Default gamut range	Custom gamut range

The first capability to be established between the calling unit and the called unit is to indicate whether JPEG mode is available. Then the second capability to be established is whether full color mode is available. Thirdly, a means is provided to indicate to the called unit that the Huffman tables are the default tables. The transmission of Huffman tables is mandatory. In addition to these three characteristics, the following four capabilities that pertain to mandatory or optional capabilities are exchanged.

The exchange of these capabilities is achieved by new bit assignments (one additional octet) to the DIS/DTC and DCS frames. The new standard for Group 3 Color Facsimile is contained in two new annexes to the current Group 3 recommendations[12,13] that were formally passed by the ITU in November 1994. The Group 4 standard is structured quite differently, but functions in an analogous manner.[1] In addition, a new color facsimile test chart was also adopted by ITU to facilitate the testing of color facsimile transmission.

The new color facsimile standards described above have been implemented and tested during 1994–1995 between private companies and successful exchanges of color facsimile images have been conducted.

3. Implementation of a Color Facsimile Machine[14,15,16]

Developing a prototype for color facsimile presents to the designers a number of unique challenges. From the architecture side it demands a very efficient integration of algorithms and architectures in image scanning, compression, color processing, communications, and printing. From the image quality point the accurate representation of scanned color input and the accurate reproduction of received color images post strict requirements on the implementation of color transformation algorithms. For example, JPEG compression related parameters, such as quantization tables, are only one set of variables that control overall image quality and system performance. One also needs to examine the complete processing pipeline, including the scanner's characteristics, the printer's color gamut, and dithering or halftoning algorithms, to make the whole process function seamlessly.

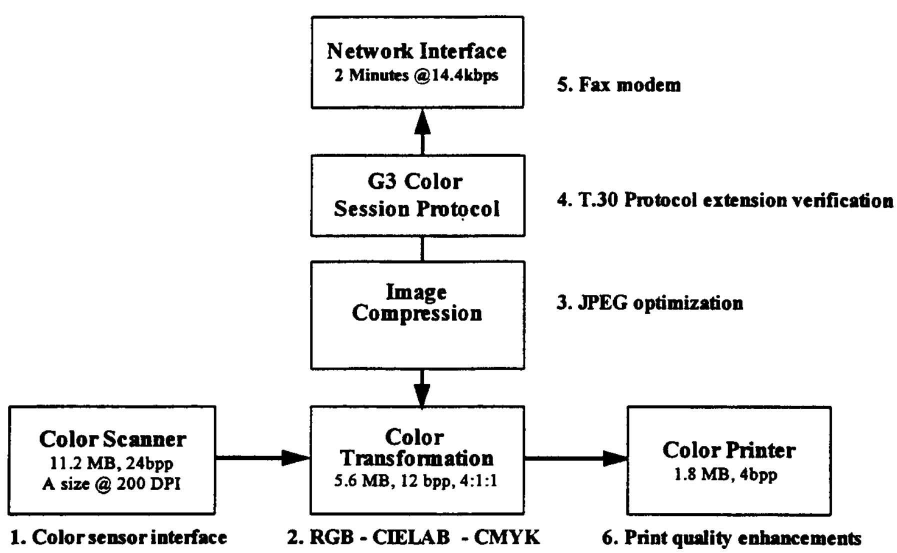

Figure 2. Color facsimile processing pipeline.

3.1 Color Facsimile Processing Pipeline

A block diagram of the color facsimile pipeline is shown in Figure 2.

The process pipeline for a color facsimile begins with the color sensor interface of the input scanner in stage 1. The scanned image data, most often in 24-bits per pixel, RGB data is then transformed into the CIELAB color space in the color transformation pipe of stage 2. At the baseline resolution of 200 dpi, an A-size color image requires 11.22M bytes of memory. The data are then JPEG compressed in the image compression pipe in stage 3.

Using a 9,600 bits/second Fax modem, experimental results showed that the effective, error free transmission is approximately 64 kbytes/min. This includes typical error correction mode overhead but no call establishment and negotiation times. Using the default JPEG quantization tables on CIELAB data, one can achieve perceptually lossless compression at compression ratios close to 20:1. At this compression ration, the color document would require more than 8 minutes of transmission time. Compared to the 20 seconds required for a typical bi-level image, this time is at least two orders of magnitude longer. For transmission times of less than three minutes, the minimum compression ratio needed should be at least 60:1. The optimization of JPEG compression is conducted in stage 3. The JPEG compressed CIELAB image data is packaged within the Group 3 facsimile protocol, in stage 4, and the facsimile transmission session is initiated with the network interface of stage 5. When the call is established then the image is transmitted.

On the receiving side, the processes progress in reverse. The called station, the receiver, answers the call and initiates the receiving protocol in stages 5 and 4. The received image data are sent to the image compression stage where they are JPEG decompressed. The data are still in CIELAB coordinates and needs to be color transformed in stage 2 to CMYK coordinates for printing, in stage 6.

Other challenges in the implementation of the pipeline include the correct implementation of T.30 protocol with the ECM (Error Correction Mode), the correct use of color space, color gamut, JPEG quantization tables, efficient communication interface and high quality hardcopy output.

3.2 System Integration

3.2.1 Hardware Environment. The hardware core of an experimental implementation of a color facsimile done at Hewlett-Packard is a 486-class personal computer (PC) running MS-DOS. The main external peripherals are a color scanner (HP ScanJet IIc) and a color printer (HP Deskjet 660C). The back plane of the PC can be used to connect either commercially available peripherals (e.g., a modem and a network interface) or custom made boards.

3.2.3 Software Environment. Fast prototyping of algorithms and system configuration requires a modular environment that allows for: a) easy integration of new routines; b) real-time control of time-critical components such as scanning and paper-feed mechanisms; and c) portability of existing and new software into a variety of computing platforms such as workstations, PCs, and DSPs or micro-controllers. As a result, a pipe-like software architecture was developed, where each pipe-module represents a specifrc function of the processing pipeline, such as JPEG encoding, JPEG decoding and color transformations. Each pipe stage operates on the minimum possible amount of data, such as a color scan line.

Figure 3 shows a block diagram ofthe software architecture.

An event manager and system monitor control real-time requests and supervise the data flow among the pipeline components. For example, the "image Input Pipeline" block (Fig. 3) includes pipe stages for color correction, color conversion, subsampling, and JPEG encoding. Each pipe stage operates independently from all others on its own data. Pipe stages can all be executed on the same processor or on different processors. This allows the replacements of compute-intensive modules with hardware accelerators and evaluation of overall performance changes.

3.2.3 Pipe Structure. The current implementation of pipe structure differs from traditional pipes (e.g., Unix

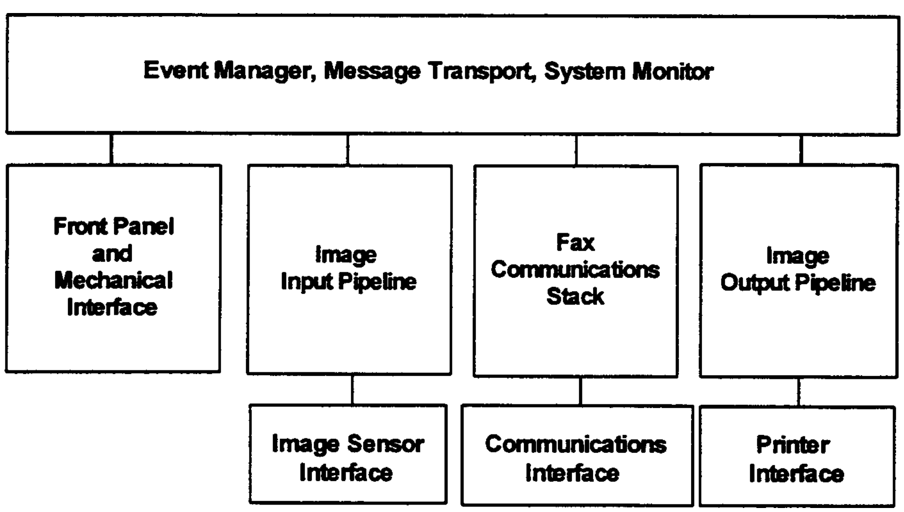

Figure 3. Software architecture of color facsimile.

pipes) in that it requires minimum system overhead and eliminates any physical copying of data between pipe stages. Pipe stages are executed via simple function calls and by passing descriptors: *Pipeline*, *PipeStage*, and *PipeRecord*.

The Pipeline structure contains information associated with the current imaging pipeline. This is useful for passing control downstream. The *PipeStage* structure contains information associated with this instance of the stage, such as any local parameters for filter coefficients, halftoning modes, color values, etc. The *PipeRecord* structure contains the data associate with the current pipeline. In the experimental implementation, the data unit is one scan line. However, each pipe unit has the flexibility to accumulate data into local buffers and to process them in larger blocks if necessary. For example, the JPEG encoder operates on macro blocks (MCUs). Each MCU consists of four 8 × 8 blocks of L*, one 8 × 8 block of a* and one 8 × 8 block of b*. Due to the subsampling of the chroma components, the JPEG encoder operates on 16 lines at a time. During regular execution, pipe routines receive a *data* message and pointers to the information associated with the next scan line data. The above structure allows each pipe stage to operate independently from other stages and minimizes data interaction and overall memory requirements.

3.3 Experimental Results

3.3.1 Transmission Time. In the experimental system, error-free communication on switched external phone lines at speeds up to 9600 bit/s V.29 speeds have been achieved, the limiting factor being the speed at which one can execute the modem functions in software. The effective facsimile transmission rate is approximately 64K bytes/min. This includes typical error correction mode overhead but not call establishment and negotiation times. Phases A and B require about 14 seconds.

3.3.2 JPEG Compression. Using the default JPEG quantization tables, one can achieve perceptually lossless compression with compression ratios close to 20:1. For such a compression ratio and a transmission rate of 64K bytes/m, an A-size color image sampled at 200 dpi will require at least 8.6 minutes of transmission time. This is far longer than the generally known time for facsimile transmission. At higher compression ratios, acceptable printing quality (exceeding present expectations of facsimile quality) can be achieved. For example, for a transmission time of less than three minutes, the minimum required compression ratio is 60:1. If a V.34 facsimile modem is used with a speed of 28.8K bit/s, this compression ratio results in a very acceptable transmission time of under one minute.

The question is how to achieve the 60:1 compression ratio. Even when the quantization tables are carefully designed to be perceptually lossless, a large q-factor will introduce artifacts, such as block artifacts in areas of constant color or ringing on text characters. The DQT elements should be chosen based on the energy within an 8 × 8 block. More quantization levels are allocated to the firequency components with the larger variance. The statistical analysis of typical images transmitted via color facsimile has allowed us to achieve the desired compression rate.

3.3.3 System Overhead. Although the user of a facsimile machine is interested primarily in the transmission time, the time required to execute the various stages in the pipeline is also important, because that will dictate the required processing power and hence the final cost of the machine. For an A-size page sampled at 300 dpi we have measured the average timings shown in Table 1 on this experimental implementation. The printing time includes dithering, generating PCL3 code, and the actual printing time on the HP DeskTet 600C. The overhead for the pipeline code is included in the various stages where it is incurred.

Table 1. Typical execution times for the stages ofa color facsimile implementation for images sampled at 300 dpi.

Pipe Stage	Time in Min:Sec
Scanning	1:55
Color mapping	2:19
Compression	1:18
Printing	2:33

3.4 Implementation Issues

3.4.1 T.30 Protocol. Two technical points should be noted during the message phase. They relate to inter-line fills and the color space. Inter-line Fills The entire page must be encoded and transmitted strictly according to the JPEG standard and the error correction mode. In particular, it is not correct to introduce null octets into an ECM frame. This will cause a transmission failure due to corruption of the JPEG data structure. Introduction of null frames may occur because the conventional implementation practice is to require an inter-line fill across error-corrected block boundaries so that individual scan lines are not split between blocks.

3.4.3 Color Management. The second point is in the JPEG encoder/decoder. Once the image is decoded from DCT coefficients to spatial coordinates, a color space transformation is required before printing or display. Most color JPEG implementations have provisions for images represented in the 3-dimensional RGB and YUV color spaces. The YLTV and the CIELAB color spaces are both luminance-chrominance spaces, yet YUV is quite different fiom the CIELAB space used for the color facsimile standard.

In addition, the CIELAB color space always requires the specification of a white achromatic stimulus. As noted earlier, the color facsimile standard assumes CIE standard illuminant D50. If the colors are bluish or yellowish, the transfonnation from device coordinates to CIELAB or vice versa might have been carried out for an incorrect reference white or iluminant. The overall problems and prospects for color management in the context of color facsimile need to be explored. Work in this direction has already appeared.[19]

4. Soft-Copy Color Facsimile[17]

During the previous meeting ofthe ITU-T Study Group 8, considerable progress towards a soft-copy extension to color facsimile has been made. The growing popularity of computer-based facsimile transmission and reception makes this a natural and timely addition. The discussion revolved around serving this application without compromising interchangeability with hardcopy devices or sacrificing color information accuracy. A detailed contribution from Japan formed the basis for such discussion. This contribution[18] detailed the various scenarios under which hard-copy and soft-copy devices might interact, and the implications of color space and gamut range upon those interactions.

The first question to be resolved is choice of interchange space. For hardcopy facsimile, CIELAB was chosen as discussed in the introduction above, but CIELAB is not commonly used in personal computers outside of certain professional applications. Most commonly, color data is stored as device-dependent RGB in one of many data formats. Many different RGB primaries, white points and gamma coefficients are used in practice. This would complicate the choice of a single RGB-type space for soft-copy facsimile. In addition, the computational burden of converting between arbitrary RGB spaces is quite similar to the computation required for conversion between CIELAB and RGB.

A larger concern was interworking between hardcopy based stand-alone color facsimile machines and computer-based soft-copy devices. Typically a calling machine does not know *a priori* what type of machine is being called. Requiring a hard-copy based machine to support an additional color space for communication to a computer-based facsimile would complicate implementation considerably. In contrast, computer-based applications have relatively flexible resources to handle color space transformations, and these resources are rapidly growing. In light ofthese discussions, the ITU has elected to retain the use of CIELAB for soft-copy facsimile transmissions, and defer addition of another color space unless and until such use becomes clearly necessary and beneficial.

The second item of discussion is choice of gamut range, the span of color space to be used in encoding color data for soft-copy facsimile application. Currently, the default gamut range is based on hard-copy devices. The range of soft-copy devices is quite different. Measured values taken using D50 and D65 illuminant to calculate CIELAB parameters yielded the following gamut envelope:[18]

$$
\begin{aligned}
L^* &= [0,\ 100],\\
a^* &= [-103.5,\ 98.8],\\
b^* &= [-106.8,\ 96.8].
\end{aligned}
$$

This range is obviously quite different from the hardcopy range listed in the introduction. The ability to reproduce blue is most notably larger for the soft-copy device, with more than 30 Delta-E units of additional range in the lower span of b*. Soft-copy devices vary considerably in their ability to reproduce colors at the very edge of the above range.

When the data to be transmitted originates from or is intended to be output to hardcopy, the current default gamut is quite adequate. In the case where the image is synthetic or taken from a soft-copy original, and intended for reproduction on a soft-copy device using the somewhat different gamut available on such a device, the default gamut will not be adequate. For this application the custom gamut option already available within the color facsimile standard can be used. This option specifies a means to select a gamut that can include the range of colors available on a soft-copy device. In addition, specification of alternate illuminant (and inferred white point) is under discussion, and will be enabled. A bit has been reserved for such specification in the DIS/DCS tables.

The specification of a default set of gamut range and white point specifically for soft-copy facsimile is currently under study. Such a gamut range would include the above range. For the time being, use of the custom gamut range option already in the facsimile standards is suggested.

5. Conclusions

We have described the new extensions to the standard ITU facsimile protocol that allows the transmission of gray-scale and full color images. We have verified the standard's viability by achieving a full implementation on a personal computer. For documents containing color images, the transmission time is approximately the same as on a conventional binary facsimile machine, however, at an incomparably superior image quality. Following the standardization of hardcopy color facsimile, the standardization work continues on the soft-copy and palette-color extensions (using JBIG coding) to the color facsimile standard. Furthermore the problems and prospects for color management in the context of color facsimile need to be explored. Work in this direction has already appeared.[19]

Acknowledgment

The author is very grateful to Giordano Beretta, K. Konstantinides, Ho John Lee and Andy Mutz for their valuable contributions to this work. He would also like to thank M. Matsuki for his leadership in the ITU Color Facsimile standardization efforts.

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✰ This paper was previously published in *SPIE,* Vol. **2658**, p. 8 (1996).