# Advantages of JPEG 2000 for Multispectral Imaging

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## Abstract

*The objective of this effort is to demonstrate and evaluate options for storing and visualizing multi-band data using JPEG 2000 format, a standard that is being adopted by several large user communities including Medical Imaging and Geospatial/ Remote Sensing. JPEG 2000, a relatively new imagery format and compression standard, has a number of features that are particularly attractive for those engaged in color and multispectral imaging. Different ways of managing and displaying color image representations of multiple-band spectral imagery were explored in this project. As JPEG 2000 becomes an increasingly accepted and applied standard, it will facilitate the sharing of images across a large population of varied users.*

## Why JPEG 2000?

Increasingly, those involved in critical color applications and studies are using more than just red, green, and blue spectral channels to acquire their imagery. While the additional channels often improve the image utility, many-band multispectral imagery also increases the requirements and complexity of systems and formats designed to handle it. Appropriate format standards help facilitate the exchange of such imagery between interested parties including those who collect the imagery and those who use it. In this regard, the CIE TC8-07 Multispectral Committee is in the process of selecting and/or defining a standard for use in distributing and storing multispectral imagery. This paper addresses the favorable characteristics of JPEG 2000, an existing standard being considered for this application.

### *JPEG 2000 vs. CIE Requirements for a Multispectral Format*

Before developing or selecting a standard, it is important to understand the requirements. In the case of multispectral imagery, the requirements shown in Table 1 have been identified. The middle column shows JPEG 2000's full compliance with the requirements, when all parts of the standard are implemented. All software is required to be in compliance with Part 1 of the JPEG 2000 standard. Implementation of other parts of the standard vary from vendor to vendor. For spectral imaging, some useful features are contained in Part 2 of the standard. The third column of Table 1 shows which part of the JPEG 2000 standard satisfies each format requirement. Some implementations of JPEG 2000 software include compliance with Part 2, but this is not universally the case. A good trend, however, is seen in the example of the Medical Community, whose adoption of the multiple component aspects of JPEG 2000 Part 2, has resulted in several more software vendors adding this capability to their offerings.

When fully implemented, JPEG 2000 not only meets the minimum stated requirements for a useful multispectral imagery format, but JPEG 2000 also contains additional useful features

**Table 1: JPEG 2000's vs. multispectral format requirements**

| CIE Multispectral Format Requirement | JPEG 2000 Requirement Satisfaction | Standard Part # |
|---|---|---|
| Platform independent | Yes | 1 |
| Planar packing available | Yes | 2 |
| API library available | Interactive protocols for clients & servers | 9 |
| Royalty free | Yes. All Part 1; All multi-dimensional Part 2 | 1; 2 (in part) |
| Metadata | Yes. XML | 1 |
| In same file as image | Yes | 1 |
| Can store output device data | Yes | 1 |
| Can store geometric registration data | Yes | 1 |
| Can store geolocation | Yes | 1 |
| Can store spectra of filters, sensors, etc. | | 1 |
| Dark noise per channel | Yes | 1 |
| Can store native tags | Yes | 1 |
| Large file size capacity | $2^{64}$ bits | 1 |
| Accommodation of a high number of channels, pixels, and bits | 16,384 bands<br>$1.8447 \times 10^{19}$ pixels<br>38 bits/pixel | 1 |
| Nonlinear bit encoding option | Yes | 1 |
| Compression | Yes | 1 |
| Uncompressed or lossless | Yes | 1 |
| Lossy compression | Yes | 1 |
| Color management | Yes | 1 |
| Storage compatible with Lab or RGB (e.g., L, a, b, ch4, ch5, ch6) | Yes | 1 |
| Image can be in terms of encoded color-imetric values under arbitrary illuminant | Yes | 2 |
| Can store arbitrary color matching function | Yes | 1 |
| Image data can be represented in terms of display device signal | Yes | 2 |
| Tone curve of each channel can be linear or non-linear | Yes | 1 |

including: (1) user-selected quality level, (2) fast browsing of large imagery, and (3) standard and customized metadata using standard Extensible Markup Language (XML). JPEG 2000 capabilities and flexibility make it suitable for many disciplines such as the textile, medical, pharmaceutical, and remote sensing industries.

### JPEG 2000 Compression Capabilities

The traditional compression paradigm is for the *creator* of an image file to regulate the image's quality. In the case of JPEG 2000, the *user* has the ability to regulate the image quality by requesting only the information necessary to provide sufficient quality do the required job. More wavelet coefficients can be added as necessary until the required quality is reached. This increases the flexibility for different users who may have different quality requirements or handling capabilities.

Since JPEG 2000 decompresses on the fly, it is unnecessary to decompress the full image at one time. This provides the capability of fast browsing of large images, since only a limited portion of the image is decompressed at any given time. The decompression is virtually immediate for the portion being displayed.

JPEG 2000 provides standard metadata with additional flexibility of allowing customized metadata through the use of XML.

Three options are available for compressing multispectral data. The first option is to simply compress each band individually. The second option is to compress the image with 3-D wavelets, and the third option is to apply a linear transformation (such as principle components) before compression. The wavelets and/or linear transformations can be applied on specified correlated groups of bands when such an approach is advantageous.

### JPEG 2000 Spectral Capabilities

Having established that JPEG 2000 exceeds the stated requirements for a useful multispectral imagery format, we will now take a look at how the features of JPEG 2000 can be used to good advantage, particularly by the color science community.

Two approaches can be used for handling the display of imagery with more than three spectral bands. First, within JPEG 2000, three specific bands out of the image can be selected to be displayed respectively in the red, green, and blue display channels. We shall see that picking bands that are close to the peaks of the red, green, and blue tristimulus values representing the human eye's spectral sensitivity (see Figure 1) gives a reasonable approximation of true color in many cases.

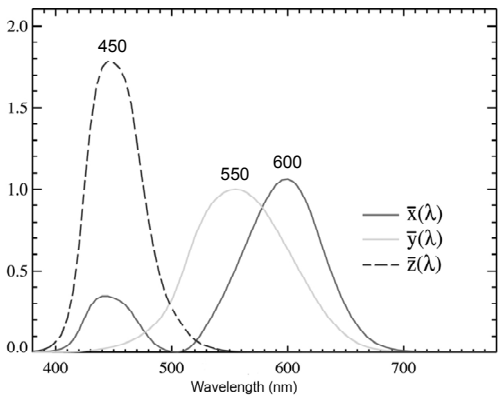
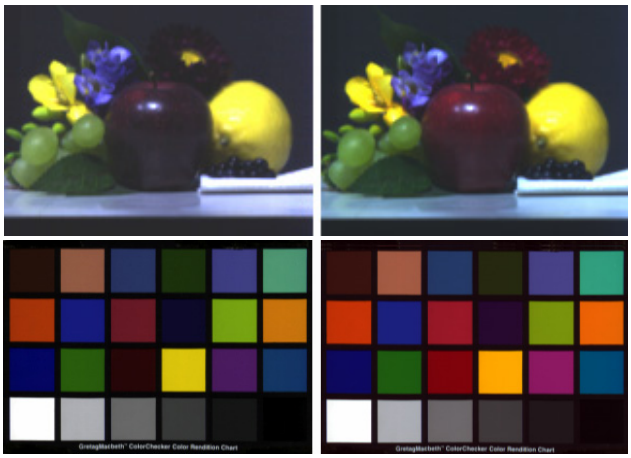



***Figure 1.*** *Tristimulus weighting functions.*

An even better representation of true color is possible by weighting many spectral bands by the full tristimulus value curves to produce three bands that best represent what the eye would see. After creation of such a set of display bands, these bands are stored with the original spectral bands, but are used only for display purposes. (The JPEG 2000 protocol calls for such bands to be stored as the first three bands in the new combined set of bands.)

So, how well does picking three of the original bands work compared to creating three bands to fully match the eye's response? The answer to this question was explored through the use of two 81-band spectral images provided for research purposes by www.multispectral.org, hosted by the University of Joensuu Color Group. Display imagery was created with both methods outlined above—one image consisting of Flowers and Fruit and the other a McBeth Color Checker (see Figure 2).



***(a) Bands 15, 35, & 45*** ***(b) RGB (81 Weighted Bands)***

***Figure 2.*** *A color image can be displayed from a spectral JPEG 2000 file by (a) using three bands closest to the peak of the eye's tristimulus values, or (b) applying a visual weighting to all available spectral bands. [81-band images courtesy of Multispectral.Org hosted by University of Joensuu Color Group]*

Some slight differences can be seen in the Flowers and Fruit images displayed with the two methods. A few color patches of the McBeth Color Checker show noticeable differences between the two methods, but most look fairly similar in the two renditions. The image created using the full set of 81 available bands is assumed to be the more accurate since it better accounts for the full spectral sensitivity of the human visual system. The fact that the two renditions of the image are quite similar suggests that for all but the most critical applications, a selection of three existing spectral bands is probably suitable for many display purposes.

### Application of ICC Profiles within JPEG 2000

Another useful feature of JPEG 2000 is that it handles storage and application of International Color Consortium (ICC) profiles for managing color from a specific capture device to a specific output display. ICC profiles are typically used to ensure color fidelity through the whole process of capture, dissemination, and display of images. This feature of JPEG 2000 is demonstrated with two examples. The first example (young lady shown in Figure 3) shows the same color image data displayed with two different color profiles. One profile is

simply a "daylight" profile that gives a "true color" representation of the image. The second ICC profile has been constructed to give a "sepia tone" to the image. The important thing to remember is that no changes have been made to the original stored data. Only the display has been modified through the use of the ICC profiles.

***(a) "Daylight" Profile*** ***(b) "Sepia" Profile***

***Figure 3.*** *Color JPEG 2000 image displayed with two difference ICC profiles [Color image courtesy of Eastman Kodak Co.]*

Typically, ICC profiles are applied to three-band images. However, the current ICC profile standard allows up to 16 spectral bands to be used. Thee-brand profiles were used in the preceding example and the one that follows.

The second example (Figure 4) actually applies both a tristimulus weighting function to the full set of spectral bands followed by ICC profiles applied to the resulting three bands. The 77-band "Meta Cow" spectral image used in this example is a creation of the Munsell Color Lab, Rochester Institute of Technology, Rochester, New York. The colors of each cow have been specifically selected using metameric pairs that match under a D65 illuminant but differ significantly under Illuminant A. The multi-band Meta Cow image was processed for display, first as it would look under Illuminant A and second as if illuminated with a D65 Illuminant. This was done through the following steps:

1. Apply red, green, and blue human visual system (HVS) sensitivity functions in 5 nm increments from 380-760 nanometers.
2. For the bandpass of each sensitivity function, sum the product of the sensitivity function with the Metacow reflectivity in the corresponding wavelengths (i.e., determine an HVS weighted value of reflectance over each visual bandpass).
3. Add the three "HVS bands" created above to the front of the original 77 Metacow bands to form an 80-band image. Store in JPEG 2000 format.
4. Create ICC profiles to apply a "D65 illuminant" and "Illuminant A" and embed in the header of the JPEG 2000 image.
5. Add a selector button to KDU_show (specific implementation software of JPEG 2000) that allows the user to select one of multiple ICC profiles embedded in a JPEG 2000 file header.

The results turned out as expected for each illuminant, with the "Illuminant A" cows being two-toned and the "D65 Illuminant" cows appearing as one solid color. Again, the difference in the two images is based on the application of ICC profiles and not a change in the stored data.


***(a) Illuminant A Profile***


***(b) D65 Illuminant Profile***

***Figure 4.*** *77-band JPEG 2000 "Meta Cow" image displayed with two difference ICC profiles*

## Conclusions & Recommendations

JPEG 2000 is a great existing imagery format and compression standard, well-suited for handling of spectral imagery. However, a few of the color and multispectral capabilities of JPEG 2000 are specified in Part 2 of the standard, whereas some vendors' JPEG 2000 software is only compliant with Part 1. The embracing of JPEG 2000 by color and multispectral communities should help drive the development of more fully-compliant software for handling spectral imagery, thus benefiting all users.

Using the capabilities of JPEG 2000, two methods can be used for displaying multi-band spectral imagery. Each method involves putting adding three display bands to the front of the dataset. Three selected bands representing wavelengths close to the peak red, green and blue eye sensitivities will generally give a reasonable rendition of the true color. For critical applications, the creation of three display bands based on a human visual system weighting applied to all available spectral bands is recommended.

ICC profiles were shown to be applicable through JPEG 2000. Such profiles can be used to create different renditions of an image from the same data set or to modify the data to account for differences in input capture sensors and output display devices.

## References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## Author Biography

*Rulon Simmons received BS (1971) and MS (1972) degrees in Physics from Brigham Young University. Employment since then has been with the Eastman Kodak Company (1972-2004) and ITT Space Systems Division (2004-present), in Rochester, NY (USA). Rulon is an image scientist whose work includes assessment and optimization of image quality, imagery compression, and spectral imaging studies. Rulon is a member of the CIE TC8-07 Multispectral Committee.*