Color Difference After Video Compression: A Comprehensive Analysis

Abstract

Color accuracy is a critical factor in video quality assessment, and video compression can introduce perceptible color differences. This article explores the useful mathematical foundations of color difference measurements, highlighting how different compression algorithms impact color fidelity. The study employs various ΔE (Delta E) color difference formulas, such as CIE76, CIE94, and CIEDE2000, to quantify the color shift caused by video compression. The results provide insights into how different video codecs affect perceptual color accuracy and the importance of evaluating these distortions in professional applications.

1. Introduction

With the increasing demand for efficient video transmission and storage, compression technologies such as H.264, H.265, and AV1 are widely used. However, compression algorithms reduce data size by removing redundant information, which can lead to distortions in color representation. These distortions impact visual perception, making color difference measurement essential for evaluating video quality. This short study aims to present the evaluation tool color distortions introduced by compression using established ΔE metrics.

ΔE (Delta E) is a **single-number measure** of how different two colors are **in a perceptual sense**—that is, how much they appear to differ **to the human eye**. A common way to calculate ΔE is by:

1. **Convert** both images (or color samples) from **RGB** to **Lab** color space.
2. **Subtract** the L, a, and b channels to get a difference:

$$\Delta L = (L_2 - L_1), \qquad \Delta a = (a_2 - a_1), \qquad \Delta b = (b_2 - b_1).$$

3. **Combine** these differences into one number (using the Euclidean distance in Lab):

$$\Delta E = \sqrt{\{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2\}}$$

- If **ΔE = 0**, the colors are *identical* in Lab space.
- A **higher** ΔE means *greater* visual difference.

Limitations of This ΔE Calculation

1. **Uses CIE76 (Basic Delta E)**
   - This formula does **not** account for human perceptual uniformity.
   - CIE76 is **less accurate** for modern color assessment.
2. **No Weighted Correction (ΔE94, ΔE2000)**
   - More advanced formulas **(CIE94, CIEDE2000)** include **hue, chroma, and luminance correction**, making them **more reliable**.

Since we want **a more perceptually accurate** ΔE calculation, the final program is designed to replace **ΔE** with **CIEDE2000.** This action mainly considers human vision **non-linearity** and **perceptual uniformity**.

CIEDE2000: A More Accurate Color Difference Metric

CIEDE2000 (ΔE2000) is an advanced color difference formula designed to **improve color perception accuracy** over older methods like CIE76 (ΔE76). It was introduced by the **CIE (International Commission on Illumination)** to better align with human vision.

Why CIEDE2000?

Human eyes perceive color differences **non-linearly**, meaning that equal changes in different colors do not look equally different. Older formulas, such as ΔE76, assume a simple Euclidean distance in Lab space, which **does not account for human vision biases**.

CIEDE2000 improves accuracy by introducing:

✅ **Hue & Chroma Compensation** – Adjusts for how humans perceive different hues differently.

✅ **Lightness Weighting** – Accounts for the fact that dark colors appear to change more than light ones.

✅ **Neutral Area Sensitivity** – Improves accuracy for near-grayscale colors.

CIEDE2000 Formula (Simplified)

The ΔE2000 formula refines **ΔE76** by adding corrections based on:

- **ΔL** (Lightness Difference)
- **ΔC** (Chroma Difference)
- **ΔH** (Hue Difference)
- **G** (Correction Factor for Chroma)
- **S_L, S_C, S_H** (Scaling Factors for Perceptual Uniformity)

The general structure:

$$\Delta E_{2000} = \sqrt{\left(\frac{\Delta L'}{S_L}\right)^2 + \left(\frac{\Delta C'}{S_C}\right)^2 + \left(\frac{\Delta H'}{S_H}\right)^2 + R_T \cdot \frac{\Delta C'}{S_C} \cdot \frac{\Delta H'}{S_H}}$$

where **R_T** accounts for hue rotations.

3. Interpreting ΔE2000 Values

ΔE2000 Value	Perceived Difference
0 – 1	Barely noticeable
1 – 2	Slight difference
2 – 3	Noticeable
3 – 5	Clear difference
5 - 10	Major difference
> 10	Different colors

4. Experimental Approach

For our measurement, we apply ΔE2000 in MATLAB to evaluate color performance and ensure our solutions remain competitive with other AVoIP solutions in the market. MATLAB provides robust tools for computing ΔE values pixel-by-pixel, ensuring accurate quantification of color deviations caused by compression.

The experiment follows these steps:

1. Convert original and compressed video frames to the CIELAB color space.
2. Compute pixel-wise ΔL, Δa, and Δb values.
3. Apply the CIEDE2000 formula to each pixel.
4. Aggregate results to determine mean and maximum ΔE values.

5. Conclusion

This article highlights the importance of precise color difference measurements in video compression analysis. By leveraging MATLAB's ΔE2000 evaluation, AVoIP solutions can be benchmarked effectively. Future research should explore AI-based enhancements to further improve color preservation in compressed video streams.

References

1. International Commission on Illumination (CIE). "Colorimetry." 2004.

2. Sharma, Gaurav, et al. "The CIEDE2000 Color-Difference Formula: Implementation Notes, Supplementary Test Data, and Mathematical Observations." Color Research & Application, 2005.

3. Gonzalez, Rafael C., and Richard E. Woods. "Digital Image Processing." Pearson, 2017.