https://doi.org/10.59476/ilpmt2026.v2i2.802

LOCAL COLOR CORRECTION FOR WEB-PAGES CONTENT HARMONIZATION

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Abstract

Modern web interfaces increasingly rely on dynamic visual content such as images, banners, and user-generated media. Unlike static layouts, these systems must maintain visual consistency despite continuous changes in content. A common issue arises from the mismatch between predefined interface color palettes and the arbitrary colors of embedded images, leading to visual inconsistency and reduced aesthetic quality. Existing color harmonization methods mainly focus on transferring color characteristics between images or improving internal coherence. However, they typically ignore the constraints of interface design systems and do not consider the semantic importance of different image regions. As a result, such approaches may distort visually significant elements while attempting to achieve global color consistency. This paper proposes a semantic-aware approach to color harmonization of dynamic visual content. The method adapts image colors to a predefined interface palette while preserving the semantic integrity of key elements. It operates in the CIELAB color space, where color relationships can be represented geometrically on the chromatic plane. The proposed method includes several stages. First, the interface palette is analyzed and a base color is selected. Then, dominant colors are extracted from the image, and the image is divided into semantically significant and secondary regions. A target harmonic scheme is defined using angular relationships relative to the base color. Color transformations are applied selectively, with stronger adjustments in secondary regions and constrained modifications in important areas. To ensure natural results, harmonic relationships are treated as tolerance regions using the ΔE metric rather than strict constraints. This allows flexible adaptation while maintaining perceptual consistency. The proposed approach supports semi-automatic color correction of dynamic content, reducing the need for manual adjustments and improving visual coherence in web interfaces.

Keywords: *color correction, color harmonization, semantic segmentation, CIELAB color space, web interfaces.*

Introduction

Modern web interfaces are increasingly built around dynamic content such as images, banners, product cards, and user-generated materials. Unlike static interfaces, where the visual structure is predefined, such systems must maintain visual consistency despite constantly changing content.

A key challenge arises from the mismatch between the color characteristics of interface elements and embedded images. While the interface palette is defined within a design system and remains relatively stable, images may contain arbitrary and often conflicting color combinations. As a result, some elements appear visually inconsistent, disrupting compositional unity and creating visual noise that negatively affects user perception.

Thus, the problem lies not in individual images, but in the absence of mechanisms for adapting them to the overall interface color scheme. This creates a need for approaches that allow dynamic visual content to be aligned with a predefined palette while preserving its semantic meaning (Weingerl, 2024).

The aim of this work is to develop and evaluate an approach for color harmonization of dynamic visual content in web interfaces. The proposed approach focuses on adapting the color distribution of images to a given interface palette while preserving visually important elements. In this context, semi-automatic approaches are of particular interest, as they allow controlled adaptation of images while minimizing visual distortion.

Related works

There are various techniques for automatically harmonizing the colors of images, most of which focus on adapting one image to another or improving internal consistency. Color transfer algorithms enable the color palette of one image to be adapted to that of another. The classic method (Reinhard E., Ashikhmin M., Gooch B. & Shirley P. 2001) operates in the decorrelated CIE LAB space and equates the mean and variance of the color components of the target image to those of the reference image – this is a simple and effective technique that produces a plausible result without complex tuning. However, such methods do not take into account the context in which the image is used. In particular, they are not designed to adapt images to a predefined interface palette, but rather to match a given reference image.

Other color-based methods employ iterative histogram correction or optimization based on minimizing the divergence between distributions. Palette-based recoloring methods allow an image to be modified by manipulating its dominant colors. For example, Chang et al. (2015) proposed an interactive tool: the color palette is extracted from the source photo, the user

edits the palette (for example, changing green to red), and the algorithm automatically recolors all pixels by mapping the old and new colors. This approach provides a controllable way to modify image colors through palette manipulation. Furthermore, image harmonization methods are often used for compositing: the colors of foreground objects need to be harmonized with the background. Modern neural network-based algorithms (e.g., Cong et al., 2019) learn to adjust selected objects in an image so that they blend 'seamlessly' into their surroundings. For instance, Lan et al. (2024) proposed the AICT method was proposed, which constructs a '3D LUT' (look-up table) for each pixel based on its position, allowing for the approximation of complex local color transformations.

Such color correction and color grading techniques utilize various models (3D LUTs, neural networks) and are typically optimized to meet visual consistency criteria. Overall, existing approaches are effective for adjusting the visual characteristics of individual images or aligning them with a reference style. However, these approaches do not address the problem of adapting images to a predefined interface palette while preserving semantic meaning. Therefore, a method that combines harmonic color modeling with semantic constraints is required.

Color Harmony

Color harmony is one of the key concepts in visual perception and design theory, describing combinations of colors that are perceived as consistent, balanced, and aesthetically pleasing. Despite the subjective nature of perception, numerous studies in psychology and design indicate that certain color combinations consistently evoke positive responses and improve the overall visual experience. Harmonious color schemes help reduce visual fatigue, enhance readability, and support a coherent visual identity of an interface (Wang S., Liu J., Jiang J., Jiang Y. & Lan J. 2022).

The concept of color harmony has been developed within artistic color theory, particularly in the works of Johannes Itten, Johann Wolfgang von Goethe, and Michel Eugène Chevreul, where attempts were made to systematize the principles of color perception. One of the most widely used models is the Itten color wheel, which represents a 12-part system including primary, secondary, and tertiary colors. This structure reflects the continuity of hue transitions and provides a visual representation of relationships between colors (Itten, 1999).

Color harmony can be interpreted not only as a subjective perception but also as a system of structured relationships, where interactions between colors can be described in geometric terms. Within this framework, har-

monic relationships can be expressed through angular distances on the color wheel, which allows their formal representation. Complementary colors are located opposite each other, forming high-contrast yet balanced combinations with an angular difference of approximately 180°. Analogous schemes consist of neighboring colors within a small angular range (approximately ±30°), resulting in smooth and visually stable compositions. Triadic harmonies are formed by three colors evenly distributed around the wheel with an angular separation of about 120°, achieving a balance between contrast and unity. More complex schemes (e.g., tetradic) extend these principles but are less commonly used in computational applications. These geometric relationships form the basis for many practical approaches to color harmony in design and visualization.

CIELAB Space

Although the color wheel provides an intuitive way to describe color relationships, it is not directly suitable for computational color analysis. Traditional color spaces such as RGB or HSL are not perceptually uniform, meaning that equal numerical changes do not correspond to equal perceived differences. Therefore, perceptually uniform color models are commonly used in image processing tasks, among which the CIELAB color space is one of the most widely adopted.

In the CIELAB model, a color is represented by three components: L, a, and b. The L component corresponds to lightness (ranging from black to white), while a represents the green–red axis and b represents the blue-yellow axis. This separation allows independent manipulation of brightness and chromatic properties, which is particularly useful in color analysis.

For color harmony analysis, the a-b plane plays a central role, as it represents chromatic information independently of lightness. In this plane, each color is defined by its coordinates, and its hue can be interpreted as an angle relative to the origin. Changes in hue correspond to rotations of the vector (a, b) around the center, while saturation is determined by the distance from the origin. This representation enables the translation of color harmony principles into a computational form, allowing geometric relationships defined on the color wheel to be applied in image processing tasks. Harmonic relationships defined on the color wheel can thus be expressed as angular transformations in the a-b plane, forming the basis for controlled color manipulation. This representation enables the direct application of harmonic transformations in the proposed method.

Methodology and equipment

The proposed method performs semantic-aware color harmonization by adapting image color distributions to a predefined interface palette while preserving visually important elements.

At the first stage, the color palette of the interface is analyzed. The primary and auxiliary colors defined within the design system are identified. From this palette, a base color is selected, corresponding to the main brand color, which is used as a reference point for further transformations.

Next, the input image is analyzed. Dominant colors are extracted, after which the image is divided into semantically significant and secondary regions. This separation can be performed using semantic segmentation methods or heuristic rules based on object detection. Semantically significant regions include objects whose color carries meaning (such as human skin, products, or recognizable materials), while secondary regions include the background and less important elements. This separation is necessary to limit the degree of permissible color modification.

Based on the selected base color, a target harmonic scheme is defined. The base color is represented in the CIELAB color space and projected onto the a-b chromatic plane. Harmonic relationships are defined as angular offsets relative to this point. For example, in a triadic scheme, additional directions are determined by angular offsets of ±120° relative to the original hue.

The hue angle in the a-b plane can be calculated as:

$$h = arctan(b / a) \qquad (1)$$

Color transformation is performed by rotating the vector (a, b) by an angle α around the origin:

$$a' = a\,cos(\alpha) - b\,sin(\alpha) \qquad (2)$$
$$b' = asin(\alpha) + b\,cos(\alpha) \qquad (3)$$

At the transformation stage, color correction is applied with respect to the semantic structure of the image. First, global adjustments of lightness (L component) and contrast are performed to align the overall tonal perception with the interface. Then, limited modifications are applied to semantically important regions to prevent visual distortions. The main transformations are applied to secondary regions, where color adjustments allow the image to be brought closer to the target harmony without affecting its semantic meaning.

To account for natural variability and avoid overly strict constraints, harmonic relationships are treated not as exact values but as tolerance regions.

For this purpose, the ΔE (CIE76) metric is used (Fraser B., Bunting F. & Murphy C. 2004). The color difference between two points in the CIELAB space is calculated as:

$$\Delta E = \sqrt{((L_1 - L_2)^2 + (a_1 - a_2)^2 + (b_1 - b_2)^2)} \quad (4)$$

In practice, a color is considered to belong to a harmonic region if its deviation from the target direction does not exceed a predefined threshold (typically ΔE ≈ 4-7, corresponding to perceptible just noticeable color differences). This allows for more flexible adjustment and accounts for the characteristics of real-world images, where strict geometric relationships are rarely preserved.

The overall pipeline of the proposed method can be summarized as follows:

- analysis of the interface palette and selection of a base color;
- extraction of dominant colors from the input image;
- segmentation of the image into semantically significant and secondary regions;
- definition of a target harmonic scheme based on the base color;
- alignment of image colors to harmonic regions in the a-b plane;
- constrained color adjustment based on ΔE tolerance thresholds.

Thus, the harmonization process can be interpreted as mapping the color distribution of an image onto a set of permissible regions in the a-b plane, defined by the selected harmonic scheme and tolerance thresholds.

Presentation of research results

To evaluate the proposed approach, a series of experiments was conducted using real-world web interface elements containing dynamic visual content (Fig. 1). The test scenario was based on a university website interface, characterized by a predefined color palette dominated by a saturated teal hue. This color serves as the primary visual anchor of the interface and was therefore selected as the base color for harmonization.

The input data consisted of photographic images embedded in the interface, primarily depicting people in educational contexts (e.g., lectures, group work, campus scenes). These images contain semantically important regions, such as human faces and skin tones, as well as secondary elements, including the background, clothing, and environmental details. In accordance with the proposed methodology, semantically significant regions were preserved with minimal color modification, while secondary regions were considered suitable for more intensive adjustments.

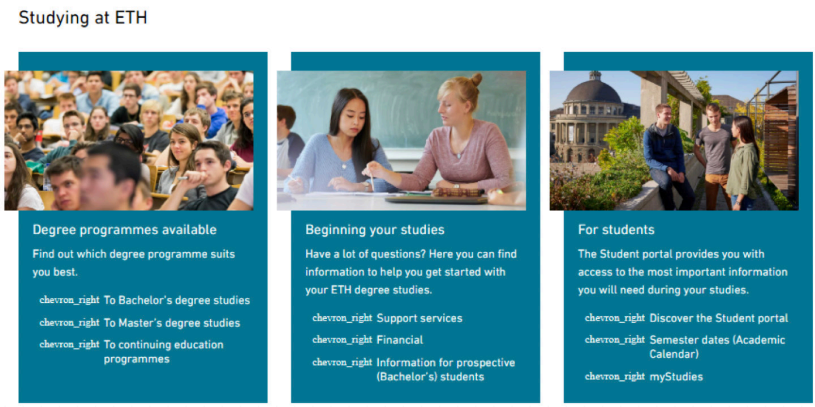


Fig. 1. Original web interface with embedded images before color harmonization

Based on the selected base color, a target harmonic scheme was defined. Empirical analysis showed that a split-complementary color scheme provides a balanced and visually expressive result in the given interface context (Fig. 2). These directions define permissible regions for color adaptation rather than strict target values.



Fig. 2. Target harmonic color scheme derived from the base interface color

Color correction was performed using a combination of standard image editing operations, including Hue/Saturation adjustment, Color Balance, and Selective Color transformations. The modifications were applied selectively: minimal corrections were introduced in semantically significant regions to avoid perceptual distortion, and stronger adjustments were applied to secondary regions to align their chromatic characteristics with the target harmonic scheme.

The results of the harmonization process are illustrated in Fig. 3, which presents the original and modified images within the interface context. Visually, the adapted images demonstrate improved integration with the interface palette, reduced color conflicts, and enhanced compositional coherence.

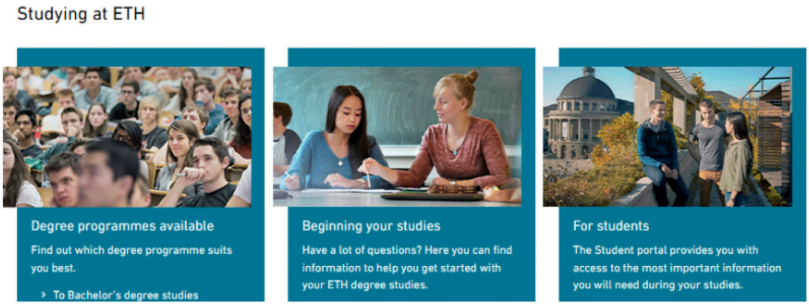


Fig. 3. Result of image color harmonization within the interface context

To quantitatively assess the effectiveness of the proposed method, the ΔE metric was used to measure the deviation of image colors from the target harmonic regions. Average ΔE values were computed for the image set before and after processing. The results are summarized in Table 1.

Table 1. Average ΔE values before and after harmonization

Metric	ΔE (before)	ΔE (after)
Image 1	10	5
Image 2	12	6
Image 3	13	6
Overall average	12	6

In addition, to verify the preservation of semantically significant regions, color changes in human skin areas were evaluated separately. The average ΔE between the original and harmonized images for these regions is 3.36, indicating minimal perceptual variation and preservation of natural appearance.

The analysis shows a consistent decrease in ΔE values after harmonization, indicating that the color distribution of the images moved closer to the defined harmonic regions. At the same time, the constraints applied to semantically significant areas ensured that critical visual elements, such as human appearance, remained perceptually natural. Overall, the experimental

results confirm that the proposed approach enables controlled adaptation of image colors to a predefined interface palette.

Conclusion

The study addresses the problem of visual inconsistency in web interfaces caused by the integration of dynamic visual content with arbitrary color characteristics. Unlike traditional color harmonization approaches, the proposed method considers both the constraints of a predefined interface palette and the semantic structure of the image.

The presented approach demonstrates that representing color relationships in the CIELAB space allows harmonic models to be formalized and applied in a computational context. The use of angular transformations in the chromatic plane provides a structured way to align image colors with selected harmonic schemes.

An important aspect of the method is the incorporation of semantic segmentation, which enables selective color adjustment. This allows the preservation of visually significant elements while applying controlled transformations to secondary regions, reducing the risk of perceptual distortion.

Additionally, the use of tolerance thresholds based on the ΔE metric introduces flexibility into the harmonization process. Instead of enforcing strict constraints, the approach allows controlled deviations, supporting more natural and perceptually consistent results.

The proposed method can serve as a conceptual and practical basis for further development of color harmonization techniques for dynamic visual content. It may be used to formulate recommendations for interface design and to guide the implementation of semi-automated or automated systems. Future work may include refinement of segmentation methods and experimental validation of the proposed approach.

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