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Towards a Universal Understanding of Color Harmony: Fuzzy Approach

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Abstract. Harmony level prediction is receiving increasing attention nowadays. Color plays a crucial role in affecting human aesthetic responses. In this paper, we explore color harmony using a fuzzy-based color model and address the question of its universality. For our experiments, we utilize a dataset containing attractive images from five domains: fashion, art, nature, interior design, and brand logos. Using a fuzzy approach, we aim to identify harmony patterns and dominant color palettes within these images. It is well-suited for this task because it can handle the inherent subjectivity and contextual variability associated with aesthetics and color harmony evaluation. Our experimental results suggest that color harmony is largely universal. Additionally, our findings reveal that color harmony is not solely influenced by hue relationships on the color wheel but also by the saturation and intensity of colors. In palettes with high harmony levels, we observed a prevalent adherence to color wheel principles while maintaining moderate levels of saturation and intensity. These findings contribute to ongoing research on color harmony and its underlying principles, offering valuable insights for designers, artists, and researchers in the field of aesthetics.

Keywords. color harmony, image analysis, fuzzy sets, aesthetics, color wheel

1. Introduction

The human brain tends to seek a visually harmonious experience. With an increase of digital affective information, automatic prediction of image harmony value is receiving more attention [1], however, still, there is no well-constructed theory to use as a guidance for practical purposes [2], [3], [4]. One reason for this is that aesthetic levels can vary across different domains [5]. Moreover, human perception is subjective by nature [6].

Color harmony is the primary driver of aesthetic preference for color schemes [7]. Several researches have shown that color harmonies can be universal [8]. Such combinations as monochromatic, complementary, analogous, etc. are widely used in art, fashion, and interior design. However, most of them only use hue as a parameter, whereas color should be described by several parameters (e.g., hue, saturation, and intensity). On the

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other hand, some studies [9], [10] show that the aesthetics level is highly context-specific. So, further research is required in order to resolve these contradictions.

This paper aims to comprehend the extent of color harmony universality. Our study goes beyond traditional approaches by considering the role of saturation and intensity alongside hue in color harmony assessment. In our earlier studies, we introduced the fuzzy color model (FHSI) [3,11,12,13] that can be used to address visual uncertainty. This study employs FHSI to investigate color harmony universality. Whether color palettes that are considered harmonious in one context are likewise considered harmonious in other contexts? Most studies focus on harmonies within 2 or 3-color palettes, but in real-world scenarios, we often deal with much more complex palettes. In our research, we analyze 8-color palettes in five domains (nature, fashion, art, logo and interior design) to better reflect the complexity found in practical applications.

The paper is structured as follows. Section I is this introduction. Section II provides an overview of studies on color harmony. Next, we recall basic ideas from our previous works on fuzzy color space in Section III. Section IV describes the methods we use in this study. Section V presents experimental results. The next Section is Discussion. Finally, Section VII concludes the paper and provides ideas for future improvements.

2. Related Work

The harmony of the color scheme is very important in color aesthetics [14,3,4]. The study of color harmony has a long history. None of the methods, however, were found to be appropriate [14]. The most common method of creating harmony is likely a selection of colors from a color wheel as recommended by Goethe [15] and Itten [16]. Other approaches proposed by Moon and Spencer [17] and Chevreul [18], are based on the examination of color relationships. Typically, these studies operate on the premise that colors achieve harmony when they are either complementary or analogous. Other methods include Matsuda's color coordination [19], and deep learning approaches [20].

The other important question is color harmony universality. Many researchers concluded that it is highly context-dependent [21]. This specificity varies from the application field we observe to the viewer's personal condition and subjective judgments. Color preference can also be influenced by different factors, such as gender, age, sex, and geographical region [22]. At the same time, some studies obtained in their experiments certain rules of color aesthetic universality [23], [4]. Specifically, some color combinations tend to arouse similar human responses in whatever context is given.

From the studies mentioned above, we can see that the mechanisms underlying the color harmonies remain controversial. As aesthetic-level prediction receives more attention, it is crucial to understand the patterns that form the basis of this area of interest.

3. Research Background: Fuzzy Color Modelling

In our earlier works [3,13,12,24,11], we presented a novel fuzzy sets based color space, FHSI, which is consistent with human perception. Our method relies on fuzzifying the well-known HSI color space (see Table 1 and Figure 1). We also provided objective measures for finding the image similarity to match human evaluation. So, fuzzy color is

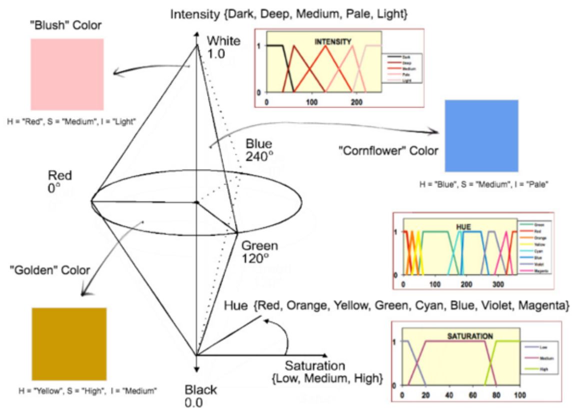


Figure 1. FHSI Color Space. Hue, Saturation, and Intensity attributes are represented as fuzzy sets.

a fuzzy subset of points of some crisp color space[25], which is the HSI space in our case [26,3]. Let D_H, D_S, D_I be domains of the H, S, I attributes respectively.

Definition 1 ***FHSI (fuzzy HSI) color*** *C is a linguistic label whose semantic is represented in HSI color space by a normalized fuzzy subset of* $D_H \times D_S \times D_I$.

From Definition 1 it is obvious that for each fuzzy color C there exists at least one representative crisp color whose membership to C is 1.

Definition 2 ***FHSI (fuzzy HSI) color space*** *is a set of fuzzy colors that define a partition of* $D_H \times D_S \times D_I$.

In other words, a fuzzy color space is a collection of fuzzy sets that provides a conceptual quantization (with soft boundaries) of crisp color space [25].

Definition 3 ***FHSI (fuzzy HSI) color palette*** *is a combination of several fuzzy colors.*

In a fuzzy color palette, each color is not crisp (point), but a fuzzy color (region). Let us take *Blush* color as an example. For the fuzzification, we take crisp inputs and transform them into fuzzy sets. For instance, if the color is in RGB format (*Blush*: R=241, G=171, B=185), we first convert it into HSI model (H = 349, S = 14%, I = 78%), then to the FHSI model (H = *Red*, S = *Medium*, I = *Light*, see Figure 1). Hue, in this case, is partially 'Red' and 'Magenta', while Saturation is partially 'Low' and partially 'Medium'.

Table 1. Description of fuzzy attributes of the fuzzy color space we proposed in earlier works [26], [13], [27].

Fuzzy variable	Term set	Domain
Hue	T = { Red, Orange, Yellow, Green, Cyan, Blue, Violet, Magenta }	X = [0, 360]
Saturation	T = { Low, Medium, High }	X = [0, 100]
Intensity	T = { Dark, Deep, Medium, Pale, Light }	X = [0, 255]

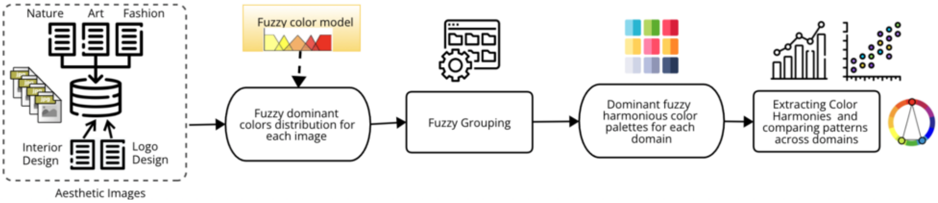


Figure 2. Proposed fuzzy approach for color harmony universality estimation

4. Methods

The proposed approach is schematically shown in Figure 2. First, we collect a dataset comprising aesthetically appealing images from five distinct domains. Then, we extract fuzzy dominant colors in each image and group the images, forming fuzzy color palettes for each domain. Finally, we extract color harmony patterns and compare them.

4.1. Data Collection and Description

- ***Fashion.*** The dataset and fuzzy color-based palettes presented in [3] were utilized. The dataset comprises looks from various sources, including prominent fashion websites like lookbook.nu, instyle.com, and dailylook.com, as well as different style communities on social networking sites (e.g., Instagram, VK, etc.).
- ***Art.*** The experiment utilized a total of 1276 artworks from the 'Best Artworks of All Time' dataset [28]. This dataset comprises famous pieces of art created by various artists representing diverse movements and eras.
- ***Nature.*** We used a dataset of pictures of natural landscapes [29]. This dataset includes real-world photos from Flickr, consisting of 100 desert pictures and 184 pictures for each of the following categories: landscapes, mountains, seas, beaches, islands, and Japan. In total, we collected 1204 images.
- ***Interior Design.*** We utilized a dataset of Modern Architecture [30]. Specifically, we focused on the Private Apartments section (U-W) and excluded images containing keywords like 'Garden,' 'Exterior,' 'Facade,' etc., as our interest was solely in interior design. This led to a total collection of 1250 interior design images.
- ***Brand Logos.*** For dominant harmonious palettes in marketing, we used the Popular Brand Logos image dataset [31], which comprises vector images of numerous well-known brand logos. A total of 1250 logos were utilized in the experiment.

4.2. Color Wheel

Johannes Itten proposed a color wheel and described graphical schemes for constructing harmonious color combinations (Figure 3) [16]. For instance, using a monochromatic color scheme means selecting one hue and its darker or lighter variations. Diametrically opposed colors are called complementary and produce the highest possible contrast. A split complementary color scheme involves one base color and two secondary colors. The triad scheme employs three colors that form a triangle on the color wheel, the square and rectangular harmonies follow the same logic. The analogous scheme entails selecting from 3 to 5 adjacent colors. Balancing saturation and lightness is vital for color harmony, especially with more colors. Our experiment explores *Monochromatic, Complementary, Split Complementary, Triad, Square, Rectangular, Analogous* harmonies.

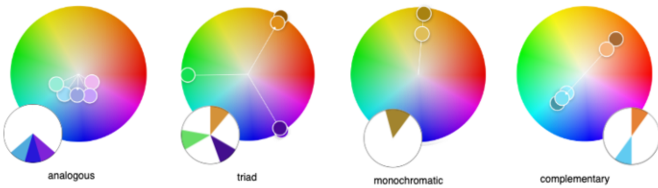
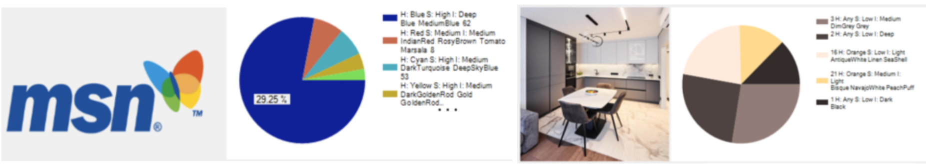


Figure 3. Color harmony rules



(a) Logo design (b) Interior design

Figure 4. Examples of extracted fuzzy color palettes

4.3. Fuzzy Palettes Extraction

Harmonious fuzzy color palettes were generated from the dataset by grouping images with similar color compositions. Examples of fuzzy dominant color detection are in Figure 4. We used the fuzzy color model with formulas for color difference and palette similarity, as detailed in [13], [12], [3]. Algorithm 1 (outlined below) identifies dominant fuzzy color palettes $P_1, \ldots, P_k$ within a domain D, employing a method for assessing image similarity using FHSI, as defined in M_1 and M_2 [26]. For a more detailed explanation, see [26]. We averaged the number of images per group for each domain, then selected dominant palettes with more images than this average for each group.

Data: dataset of images $M_1, \ldots, M_n$ in some domain D
Result: list of fuzzy dominant color palettes $P_1, \ldots, P_k$ in D
$FuzzyPalettes \leftarrow$ an empty list;
while *not at end of dataset* **do**
  read current image M_i;
  $FP_i \leftarrow$ FindFuzzyDomColors (M_i);
  $Dp_{avg} \leftarrow$ FindAvgPercDif (M_i);
  ... `/* the perceptual difference` Dp_{avg} `is found between` FP_i `and members of each fetched harmonious group. See Algorithm 1 in [3].                */`
  if *minimal* $Dp_{avg} \geq$ *diffThreshold* **then**
    form a new Palette and add M_i to it. Add Palette to $FuzzyPalettes$
  else
    add M_i to a palette in $FuzzyPalettes$ with which M_i has minimal Dp_{avg}.
  end
end
return $FuzzyPalettes$;

Algorithm 1: Extracting fuzzy dominant palettes

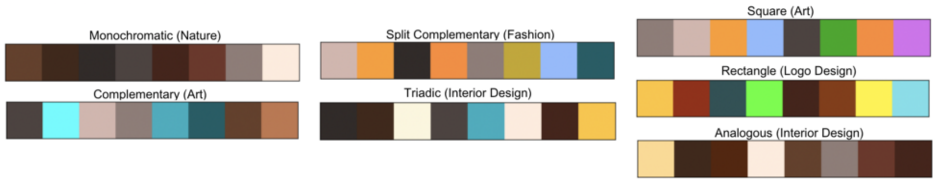
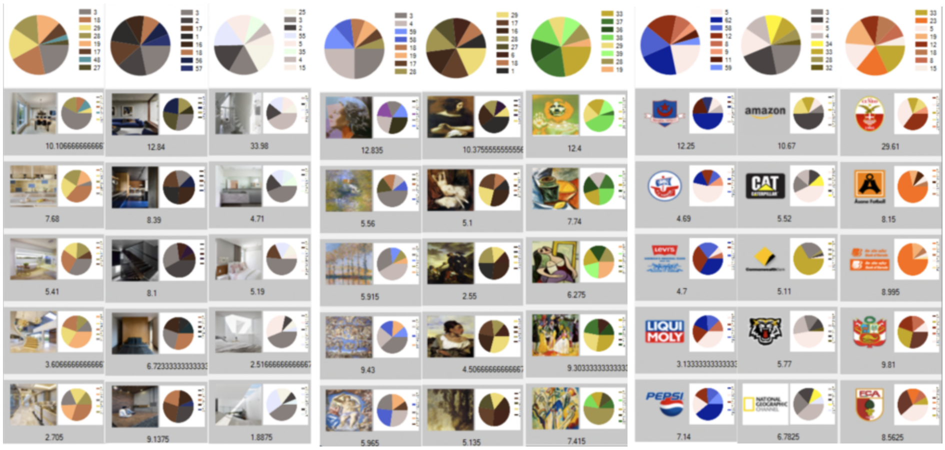
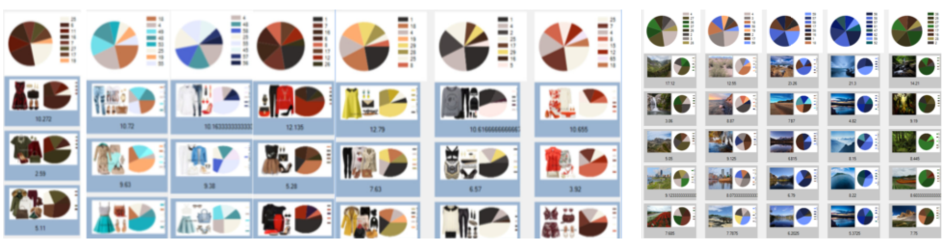


Figure 5. Examples of color palettes associated with certain harmonies



(a) Interior (b) Art (c) Logo



(d) Fashion (e) Nature

Figure 6. Examples of fuzzy dominant palettes and representative images extracted from considered domains

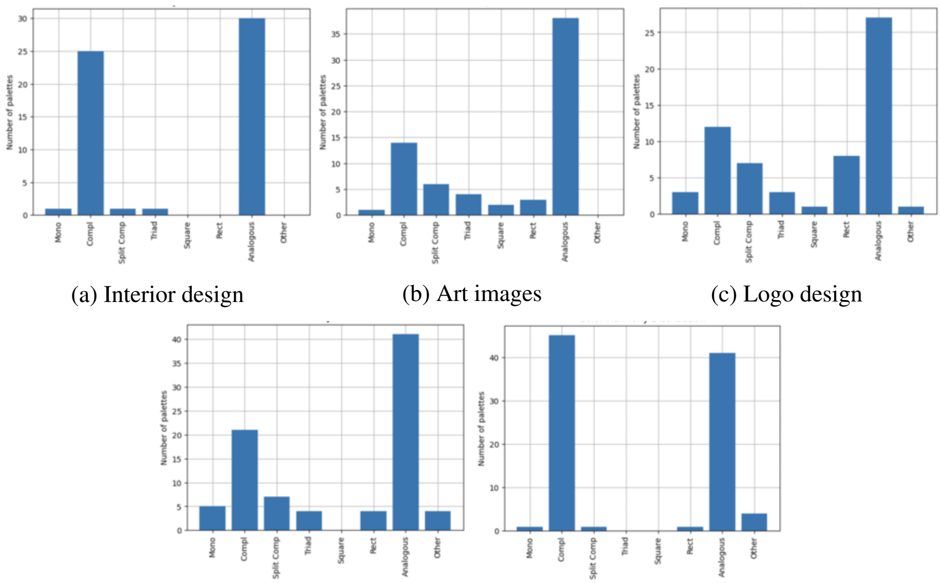
5. Experimental Results

We processed datasets with Algorithm 1 to obtain fuzzy color palettes for each context. In the *Art* domain, we found 46 groups of similar palettes. See Figure 5 for specific harmony-related color palettes, and Figure 6 for dominant palettes from various domains with accompanying images.

We identified colors on the RGB wheel, examined tertiary hues (12-split), and computed harmonies. The comparative results are in Table 2 and Figure 7. Most schemes adhered to color wheel relationships, but some fell into the *'Other'* category, deviating from these norms. Some rules like 'Triad,' 'Square,' and 'Rectangle' were less frequent, while 'Analogous' and 'Complementary' harmonies prevailed in all domains. Note that

Table 2. Summary of harmonious dominant fuzzy palettes from considered domains

Context	#Palettes	Top harmony	Other, %	Mean I	Mean S	Top Fuzzy Colors
Fashion	59	Analogous	6.8	0.50	0.40	
Nature	62	Complimentary	6.5	0.53	0.46	
Logo Design	34	Analogous	2.9	0.49	0.48	
Interior Design	37	Analogous	0	0.47	0.36	
Art Images	46	Analogous	0	0.46	0.40	



(a) Interior design (b) Art images (c) Logo design

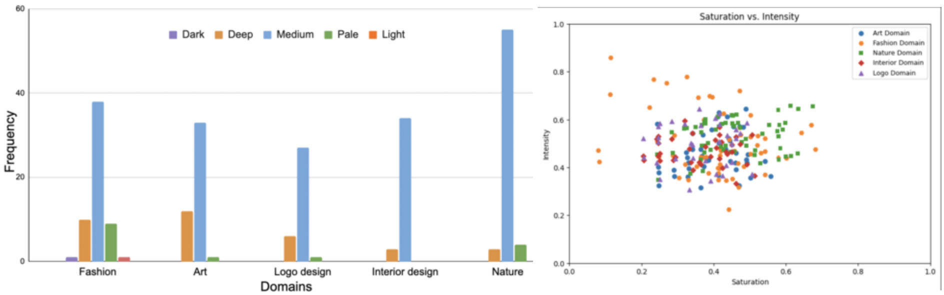
(d) Fashion (e) Nature

Figure 7. Distribution of Color Harmonies among considered domains

one palette could have multiple harmony schemes, like ’Analogous’ and ’Triadic,’ due to our use of eight-color palettes.

Figures 8b and 8a show that color harmony based on the color wheel relates to specific *Intensity* and *Saturation* levels. Even when following color wheel relationships like ’Triadic,’ variations in saturation and intensity impact harmony. In the majority of harmonious schemes, consistency in adhering to color wheel rules aligns with ’medium’ *Saturation* and *Intensity*. This holds across all contexts. Overall, the experimental results suggest that while color harmony is largely universal, some context influence remains.

The current paper explores universal harmony patterns using fuzzification across diverse contexts. The future phase will formalize these patterns as fuzzy rules for predicting image harmony. We’ll illustrate with a simple example, evaluating ’Color Harmony’ using three fuzzy variables: Color Wheel Correspondence (C), Saturation (S), and Intensity (I), each with terms like ’low,’ ’medium,’ and ’high.’ We then apply fuzzy rules connecting these variables to ’Color Harmony.’ For instance: *”IF (C is ’high’) AND (S is ’medium’) AND (I is ’medium’), THEN Color Harmony is ’very High.”* This process concludes with defuzzification, yielding the crisp color harmony value.



(a) Distibution of fuzzy intensities across domains

(b) Trends in *Intensity* and *Saturation*

Figure 8. Distribution of intensities. Fuzzy partition *(Dark, Deep, Medium, Pale, Light)* is shown in Figure 1.

6. Discussion

Compared to Itten's focus on balanced color combinations [16], favoring analogous or complementary pairs for harmony, our experiments affirm the prevalence of these pairs. Yet, our results diverge from Itten's view, showing a tendency for mid-range S and I values in harmonious images. Our findings align with Granger's work [32], emphasizing the significance of consistent saturation and intensity levels for harmony. Across five domains, we observed saturation and intensity clustering around mid-ranges, confirming their consistency. Overall, our study confirms the idea that color harmony often relates to color wheel schemes, as discussed by Itten, Munsell, and Ostwald [33].

The obtained results support the idea of the universal nature of color harmony while also highlighting its sensitivity to context. Our results are consistent with those reported in [14] regarding general patterns of color harmony. Some works, however, suggest that color harmony exhibits both universal and domain-specific characteristics [5].

7. Conclusion

This paper explores the context-dependency of color harmony using a fuzzy approach. We analyzed harmony in art, fashion, nature, interior design, and branding. Our results highlight the importance of color wheel principles and the critical role of saturation and intensity. Most harmonious schemes follow 'Analogous' and 'Complementary' color wheel rules, balancing medium saturation and intensity.

The study has limitations, with datasets potentially not fully representative of real-world diversity. Expanding dataset variety and size can enhance generalizability. In future work, we aim to introduce a fuzzy inference system using rules based on color wheel correspondence, saturation, and intensity. We also plan to include user evaluations for deeper insights into color harmony.

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