Color-Naming System Using Fuzzy Set Theoretical Approach

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Abstract

The present study considered a fuzzy system in which vague colors can be expressed in words (usually adjectives). The words (color names) consist of a hue name with its modifier, or a hue name only. This system can translate input hue system data to color names (output). Triangular membership functions are applied to the hue angle, and conical membership functions are applied to the relationship between lightness and saturation. By treating the membership function of tone modifier as a fuzzy relation between lightness and saturation, we can easily obtain the membership grade of a target modifier as an output fuzzy set from projection of an input fuzzy set. Three modifiers associated with respective grades indicate vague colors. The present paper proposes a fuzzy system that can determine a few tone modifiers (e.g., dark, dull, deep, etc.) suitable for color names in common use. For system evaluation, vague colors for 5 principal hues, 124 boundary points among neighboring JIS modifiers are used.

I. INTRODUCTION

The human eye can skillfully distinguish a large number of colors, and most people can also easily present color names based on subjective expression of a color. However, presenting color names objectively is difficult. Therefore, a fuzzy system in which colors can be expressed in words (modifier and hue name, or hue name only) has been considered. A method for obtaining hue names has been reported in a previous paper [2]. However, the main problem involved in obtaining a tone modifier is the method of creating membership functions on the tone plane within the same hue. A color-naming technique with tone expressions using the fuzzy set theoretical method has not been studied.

In this study, conical membership functions [1] are used on the tone plane [4]-[6]. Such the system will help us to determine keywords of goods and arts expressed by characteristic colors, although color names of this system slightly differ from those determined on the basis of Japanese Industrial Standards. This fuzzy set theoretical approach is useful not only for color-naming technique, but also for visual aids, information retrieval, and similar applications.

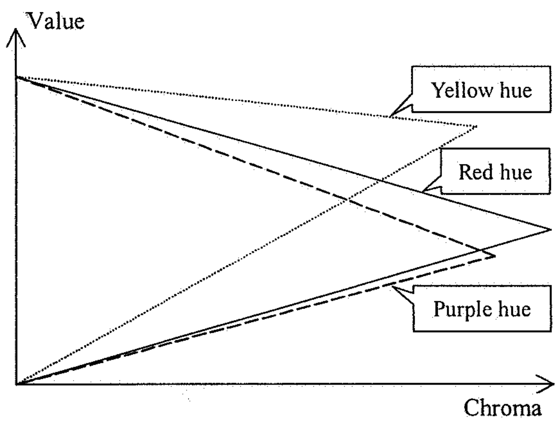

Fig. 1. Schematic tone triangles and modifiers in the HVC system.

II. COLOR SPECIFICATION OF JAPANESE INDUSTRIAL STANDARDS SYSTEM

The Japanese Industrial Standards (JIS) system was developed by reference to the ISCC-NBS method (1953). In Table I, chromatic color names according to JIS; specifically, ten hue names (5 principal hues and 5 intermediate hues in the Munsell system), are qualified by dark, light, deep, pale, dull, vivid, etc. Hue specifies one of ten hues. Table I shows tone modifiers indicating mutuality between value and chroma. The chroma scale ranges from zero chroma (left) to the highest chroma (right), with zero corresponding to an achromatic color. The value scale is from zero value (lower part) to the highest value (upper part). Table I corresponds to Fig.1. Dark red is an

TABLE I
RELATIONSHIP BETWEEN HUE AND TONE MODIFIERS

Achromatic	Chromatic color			
white				
	very pale			
light gray		pale		
	light grayish		light	
gray	grayish	dull	Hue	vivid
	dark grayish		deep	
dark gray		dark		
	very dark			
black				

TABLE II
SCALE DIFFERENCES BETWEEN THE HVC AND HLS SYSTEMS

	HVC system		HLS system	
Hue	Hue	(0-100)	Hue angle	(0-360)
Tone	Value	(0-10)	Lightness	(0-1)
	Chroma	(0-∗)	Saturation	(0-1)

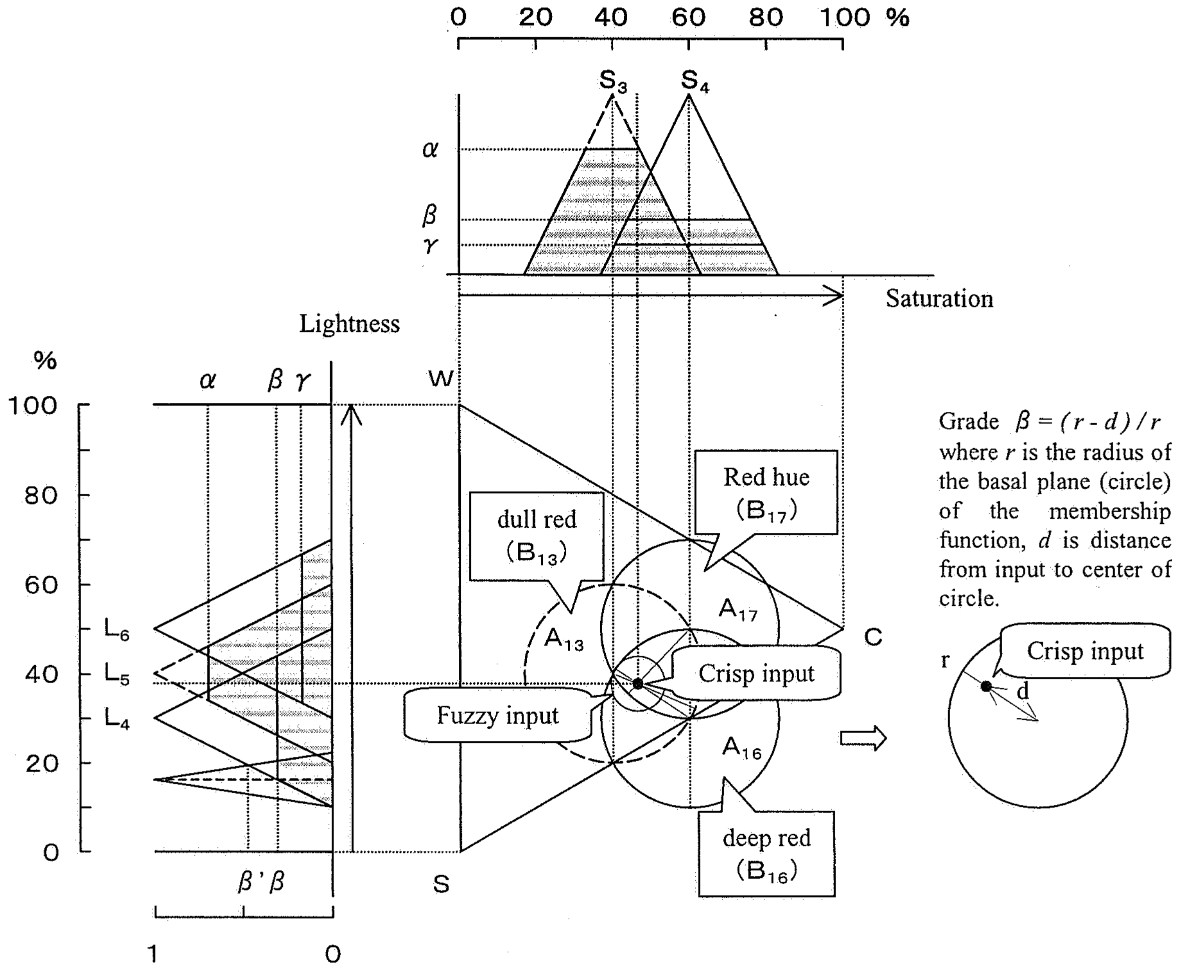

Fig. 2. Grades of color names for crisp and fuzzy input.

example of a color specification using color names: [tone modifier, e.g., dark] + [hue name, e.g., red].

III. Methods and Results

Table II shows scale differences between the HVC system [H: hue, V: value, C: chroma] and the HLS system [H: hue, L: lightness, S: saturation]. The symbol * denotes that the highest chromas are not fixed. No maximum is set for the chroma scale; the highest chromas depend on the hue and the value [3]. Fig.1 shows various triangles with tone modifiers (Table I), by correspondence between value (ordinate) and chroma (abscissa). Yellow hue and purple hue are clearly different from red hue; red hue is associated with a triangle approximating isosceles, whereas yellow hue and purple hue are associated with a triangles that clearly are not isosceles. Obtaining a tone modifier from the HVC system is difficult; in some cases the same membership function of a cone cannot cover tone triangles for different hues. However, the highest chromas can be fixed by a cosine approximation of value and chroma as a function of hue [2].

Therefore, our system adopts the HLS system rather than the HVC system [4]-[6]. Tone modifier is obtained by means of conical membership functions corresponding to each modifier on the tone plane, as shown in Table I. In the HLS system (cf. Table III), tone is expressed by a substantially isosceles triangle, in the manner of the red hue shown in Fig.1. Conical membership functions can be derived at high density. The input fuzzy set on the lightness-saturation plane corresponds to each modifier.

The color names and tone modifiers are the same as those used under JIS. Points of difference are as follows. Two membership functions are used, for constructing 'gray' of achromatic color, and 'dull' and 'vivid' of chromatic color. Further, 'very vivid' is added as a modifier denoting maximum saturation, because these modifiers occupy a large region on the plane. Reddish achromatic colors (as shown in Fig.3) are not including here. The conical membership function with each grade represents the output conical frustrum.

Assuming that red is selected for the hue, target tone modifiers are 'dull,' 'deep,' and 'no modification.' These grades range from 0 to 1, and the color is selected from 'dull red,' 'deep red,' and 'red.' The fourth color, 'dark red,' can be entered, but this color is omitted here, because the grade is so

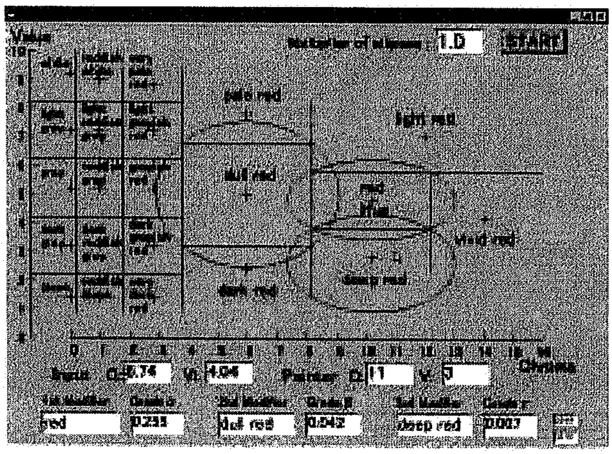

Fig. 3. Membership functions of different-shaped oval cones for each modifier in the HVC system.

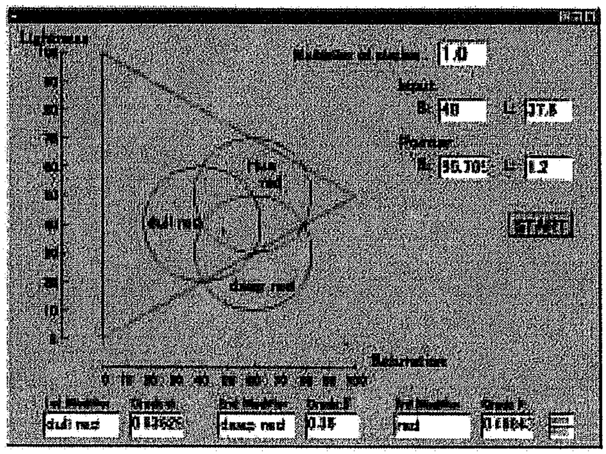

Fig. 4. Membership functions of identical circular cones for each modifier in the HLS system.

low. Namely, 'dull red' of the highest grade α, and also 'deep red' of β and 'red' of γ are selected. Only 'dull red' can be determined from color specification of JIS; however, in this system the grade order *i)* 'dull red,' *ii)* 'deep red,' and *iii)* 'red' can be obtained.

Fig. 2 shows grades of modifiers for crisp input. α, β, and γ can easily be obtained from the distance between center of each conical membership function and crisp input; determining grade is equivalent to calculating the ratio $\beta = (r - d) / r$, where r is the radius of the basal plane (circle) of membership function, and d is the distance from input to the center of the circle. For fuzzy input, β' can be obtained simply by placing the center of projection (narrow triangle) of the fuzzy input together at the corner of a trapezoid (shaded areas) having height β, which depends on distance ratio. α' and γ' can also be obtained in the same way. Each grade for fuzzy input is clearly higher than that for crisp input ($\beta' > \beta$).

An idea adopted in this study is to use fuzzy sets with conical membership functions corresponding to each modifier on the tone plane. In the HVC system (Fig.3), for each modifier we can construct membership functions of different-shaped oval cones to 22 blocks (composed of rectangles, trapezoids, or triangles). The membership functions are laid to overlap each other. The blocks show each area of modifiers for a hue in JIS, and exact reddish achromatic colors are included here. Membership functions are elliptical cones (oval cones), and ovals serve as basal planes of membership functions. Ovals intersect 3 or 4 corners of each block. If a block is composed of a rectangle, the oval intersects 4 corners. If a block is composed of a triangle or trapezoid, the oval intersects 3 corners. Usually, an oval circumscribes a rectangle, and the 4th corner can be visualized from the 3 corners by reference to the long side and the short side of the rectangle. The ratio of long diameter to short diameter for an oval is equal to the ratio of the long side to the short side of the corresponding rectangle, these ratios differ according to hue. Boundaries between modifiers have been clearly defined by JIS. For chromatic color names fixed under JIS, twenty hue names (5 principal hues, 5 intermediate hues, etc.), are qualified by dark, light, deep, pale, dull, vivid, etc.. For example, dark red is composed of [tone modifier; i.e., dark] + [hue name; i.e., red]. However, for each hue we have to create 22 different membership functions of oval cones. Namely, we need at least 440 cones (= 22 cones x 20 hues) for the HVC system. If we can use identical circular cones instead of different oval cones, only 22 membership functions of cones are sufficient to construct this system. Therefore, this study adopts the HLS system (Fig.4) rather than the HVC system (Fig.3).

When a crisp input falls within the base (circular area) of a conical membership function, each membership grade for crisp input can be obtained simply from distance between the center of the conical membership function and crisp input. Determining grade is equivalent to calculating the ratio $(r - d) / r$, where r is the radius of the base (circle) of the membership function, and d is distance from input to the center of the circle. For fuzzy input, each grade can be obtained from the projection of fuzzy input and the projection of the conical membership function, by reference to the calculated grade for crisp input.

IV. System Evaluation

The HVC system comprises 22 blocks composed of rectangles, trapezoids, and triangles (JIS system in Fig.3). The corners of blocks, 23 boundary points for red hue (in Table III), are used for system evaluation. Table III shows boundary points between combinations of 2, 3, and 4 areas. Within each grade, three candidate modifiers are associated with each boundary point (s, l). The percentage of correct outputs (neighboring JIS modifiers) for vague inputs (boundary points) is 76.6% for the 1st modifier, 63.1% for the 2nd modifier, and 56.3% for the 3rd modifier, the figures representing averages for 5 principal hues. At one boundary point between "vivid red" and "light red" (No. 1), under the previous color-naming system [4]-[6], the 1st modifier is "vivid 2 (darker)," the 2nd modifier is "vivid 1 (lighter)," and the 3rd modifier is "very vivid." The system recognizes "vivid" as corresponding to these modifiers (see Table III). At "very pale red" and "reddish white" (No. 18), the 1st modifier is "white," the 2nd is "very pale," and the 3rd is "light gray." The 1st modifier should be "reddish white," because saturation s = 7.3. In the previous study [4]-[6], membership functions (A_1 A_6) were considered achromatic

TABLE III
BOUNDARY POINTS (s, l) AMONG NEIGHBORING JIS MODIFIERS AND THREE CANDIDATE JIS-LIKE MODIFIERS WITH RESPECTIVE GRADES, IN RED HUE

No.	Neighboring JIS modifiers	s	l	1st modifier	Grade	2nd modifier	Grade	3rd modifier	Grade
1	vivid-light	83.6	47.7	vivid 2	0.584	vivid 1	0.368	very vivid	0.284
2	vivid-light-red	63.7	47.7	no modifier	0.804	vivid 2	0.192	vivid 1	0.062
3	vivid-red-deep	64.3	31.9	deep	0.790	vivid 2	0.206	no modifier	0.076
4	pale-light	42.8	76.7	pale	0.794	light	0.182	dull 1	0.156
5	light-pale-dull	42.8	62.7	dull 1	0.817	light	0.170	pale	0.126
6	light-red-dull	42.8	52.7	dull 1	0.615	dull 2	0.353	grayish	0.007
7	red-deep-dull	42.8	32.7	dull 2	0.615	dark	0.353	deep	0.242
8	deep-dull-dark	42.8	26.7	dark	0.643	dull 2	0.324	deep	0.236
9	deep-dark	42.8	21.4	dark	0.858	deep	0.139	dull 2	0.062
10	pale-very pale	18.8	90.6	very pale	0.937	white	0.060	light gray	0.029
11	pale-very pale-light grayish	18.8	79.6	light grayish	0.517	very pale	0.477	light gray	0.186
12	pale-dull-light grayish	18.8	65.7	light grayish	0.778	grayish	0.213	gray 1	0.137
13	dull-light grayish-grayish	18.8	59.6	grayish	0.517	light grayish	0.477	gray 1	0.186
14	dull-grayish-dark grayish	18.8	39.7	dark grayish	0.512	grayish	0.482	gray 2	0.186
15	dull-dark-dark grayish	18.8	29.7	dark grayish	0.942	dark gray	0.052	gray 2	0.037
16	dark-dark grayish-very dark	18.8	19.7	very dark	0.512	dark grayish	0.482	dark gray	0.186
17	dark-very dark	18.8	9.4	very dark	0.937	black	0.060	dark gray	0.029
18	very pale-reddish white	7.3	93.1	white	0.532	very pale	0.425	light gray	0.273
19	very pale-light grayish-reddish white-light reddish	7.3	81.1	light gray	0.679	very pale	0.289	light grayish	0.216
20	light grayish-grayish-light reddish-reddish gray	7.3	61.3	gray 1	0.678	light grayish	0.295	grayish	0.210
21	grayish-dark grayish-reddish gray-dark reddish	7.3	41.1	gray 2	0.679	grayish	0.289	dark grayish	0.216
22	dark grayish-very dark-dark reddish-reddish black	7.3	21.1	dark gray	0.679	dark grayish	0.289	very dark	0.216
23	very dark-reddish black	7.3	7.1	black	0.525	very dark	0.427	dark gray	0.282

vivid: vivid 1 (lighter), vivid 2 (darker), and very vivid. dull: dull 1 (lighter) and dull 2 (darker). gray: gray 1 (lighter) and gray 2 (darker).

colors, with accompanying vagueness. However, this is incorrect in color specification. Therefore, in the improved color-naming system, vagueness of membership functions (A_1 A_6) corresponds to fuzzy sets (B_1 B_6) of hue modifiers. These hue modifiers are reddish white, light reddish gray, reddish gray 1, reddish gray 2, dark reddish gray, and reddish black. If the saturation s is equal to zero, some parts of membership functions (A_1 A_6) correspond to achromatic colors (white, light gray, gray 1, gray 2, dark gray, and black). Namely, projection S_0 of these fuzzy sets is a *singleton* on the saturation axis (not illustrated in Fig.2). In the improved system the percentage of correct outputs for vague inputs (in 5 principal hues) is 98.4% for the 1^{st} modifiers, 84.7% for the 2^{nd} modifiers, and 57.9% for the 3^{rd} modifiers. The percentages of the 1^{st} and 2^{nd} modifiers represent increases of about 20%, but the percentage for the 3^{rd} modifier represents almost no change.

V. CONCLUSIONS

This paper proposes a fuzzy system that, for a known hue name (e.g., red), can extract a few tone modifiers (e.g., dark, dull, deep, no modification, etc.) suitable for color names in common use. The system is constructed by fuzzy sets with conical membership functions that correspond to respective JIS-like modifiers on the tone plane. Achromatic colors are treated as a subset of chromatic colors. The system also extracts, in a simple manner, the membership grade of a modifier from projection of a conical membership function. Vague colors among neighboring JIS modifiers are indicated by three candidate modifiers within each grade. The improved system shows high performance in terms of percentage of correct outputs for vague colors.

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