FUZZY INTERFACE SCHEME FOR COLOR SENSOR SYSTEM

S.T.Patil[1], R. R. Mudholkar[2]

Department of Electronics, Shivaji University, Kolhapur[1, 2]
patil.snehalata17eln@gmail.com
rrm_eln@unishivaji.ac.in

ABSTRACT

The shade of color in the visible range not only depends on the wavelength but it also a function of intensity. This is vital in many applications, where color matching is highly desirable. In view of this we have made and attempt to assign some degrees to basic colors and shades around them. Since color identification by its shade a matter of degrees and involves the uncertainty. To circumvent this problem we thought of an idea of exploring the Fuzzy Logic Inference, where uncertainty in color identification can be handled via Fuzzy Sets and Fuzzy Reasoning. In this paper we communicate the development of Fuzzy Inference System (FIS) that can compute the degree for a color taking both the wavelength and intensity in to account. The results found are very interesting and degree of color varies saw-tooth fashion when visible color spectrum being scanned from one color to adjacent color. The hardware implementation is under consideration and we are proposing to build it around semiconductor color sensor PD153 and PIC 16F877.

KEYWORDS

Visible Color Spectrum, Color Identification, Color Shade, Fuzzy Sets, Fuzzy Reasoning.

1. INTRODUCTION

The history shows some traces of foundational ideas of Fuzzy Logic in the philosophical thoughts put forth by Buddha, who lived in India during 500 BC. His philosophy was based on the thought that the world is filled with contradictions, that almost everything contains some of its opposite, or in other words, that things can be *A* and*not-A* at the same time. Obviously there exists a clear connection between Buddha's philosophy and modern Fuzzy Logic Theory. Since then up to 1965 the concept of Fuzzy Logic came across in many people's mind such as Romans, Aristotle and many more. But the real era of Fuzzy Logic began in the 1965 with the proposal of fuzzy set theory by Lotfi Zadeh. Zadeh [1973] based on the "*Principle of Incompatibility*", which claims that in any application when complexity of a system exceeds a certain limit then precise and meaningful description of system behavior becomes impossible. According to Prof. Zadeh this was the origin of Fuzzy Logic. Fuzzy logic is a huge concept including fuzzy set theory, fuzzy measure and others. Fuzzy logic tries to measure that degree and to allow computers to manipulate such information. Fuzzy logic has been applied to many fields, from control theory to artificial intelligence.

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Color perception is significantly determined by the intensity and wavelength. Many a times a simultaneous consideration of both these parameters is ignored. In many delicate applications of color detection such as investigation of currency fraud by precise color identification is vital. In biological field the artificial ripening of fruit is also becoming a need of time which depends on the detection of color of fruit in ripening state and sensing of leaf color for their growth progress detection etc. We present here a novel use of fuzzy logic in color sensation and detection system in respect to intensity and wavelength of color. The need of precise color sensing with respect to intensity in critical applications is the origin of the work reported in this paper. The color sensor being used in this work gives the corresponding voltage range for various colors. Sensor's output is given to the PIC which decides the wavelength of sensed color. The wavelengths are sent serially to the Fuzzy Query Instrument where manipulations are carried out to compute the exact wavelength, intensity and the degree of color (which is the exactness of color) based on the Fuzzy Reasoning. For intensity calculation and degree of the color the Fuzzy Toolbox of MATLAB has been used. A large amount of numerical data generated in the form of MATFILE. This data is used by Adaptive Neuro-Fuzzy Inference System (ANFIS) Tool, which is located in Fuzzy Toolbox itself. It automatically creates required amount of input-output membership function and linear equations representing the consequence part of inference rules for color identification.

2.FUZZY REASONING PROCESS

There are two methods of fuzzy reasoning one is direct and second is indirect method. Amongst them most popular is the direct method; because indirect methods have a relatively complex reasoning mechanism.

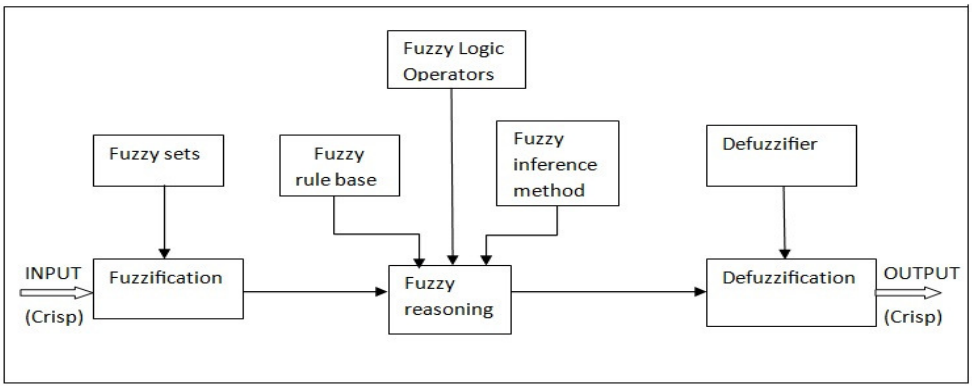

Figure1. Structure of rule- based fuzzy model

Direct method fall into two categories: Mamadani's Direct Method and Takagi-Sugeno-Kang's (TSK) fuzzy Modeling. The Takagi-Sugeno -Kang's method was introduced in 1985 [16], it is similar inference process, fuzzifying the inputs and applying the fuzzy operator, are exactly the same. The main difference between Mamadani's and Sugeno is that the Sugeno output membership functions are either linear or constant. Because it is a more compact and computationally efficient representation than a Mamadani's system, the Sugeno system lends itself to the use of adaptive techniques for constructing fuzzy models. These adaptive used to customize the membership functions so that the fuzzy system best models the data.

In the present work the ANFIS of MATLAB has been used. Using a given input/output data set, the toolbox function *anfis* constructs a fuzzy inference system (FIS) whose membership function

parameters are tuned (adjusted) using either a back propagation algorithm alone or in combination with a least squares type of method.

3. THE COLOR- A MATTER OF DEGREE

Color is the visual perceptual property found in human. This helps the human to categories color as red, green, blue and others. Color derives from the spectrum of light interacting in the eye with the spectral sensitivities of the light receptors. Our eyes are sensitive to light which lies in a very small region of the electromagnetic spectrum labeled 'visible light'. This visible light corresponds to a wavelength range of 380 - 700 nanometers (nm) for violet through red. In photometry the luminous intensity is a measure of the wavelength-weighted power emitted by a light source in a particular direction per unit solid angle based on the luminosity function a standardized model of the sensitivity of the human eye. Thus the intensity is the number of photons, wavelength is the color. From this we can make a conclusion that intensity is nothing but the energy evolved by the color in the form of photon. The relation between the wavelength and intensity is as given by equation (1).

$$e = h.f$$

$$\therefore e = \frac{c.h}{\lambda} \tag{1}$$

Where, $e$is energy in joules
$h$is Plancks constant=6.626× 10^{-34}Joule/sec
$f$is frequency in cycles/sec
$c$is light velocity= 3× 10^{3} meters/sec
$\lambda$is Greek letter lambda and it represents wavelength in meters

As we move across a visible spectrum from violet through red, the intensity of color decreases from one color to other as shown in fig.2. e.g. the wavelength of violet color is in the range of is380-450 nm and intensity326-316 KJ/mole, thus it is maximum at 380 nm wavelength and decreases towards 450 nm . At 450 nm it becomes starting point for indigo color. In others words we can say that, at 380nm wavelength and 326 KJ/mole intensity the degree of violet color is 100%, at 450nm wavelength and 316 KJ/mole intensity it becomes 0%.At the same time at 450nm wavelength and 316 KJ/mole intensity the degree of indigo color becomes 100%. Thus color is a matter of degrees in terms of wavelength and intensity and these degrees need for the exact indication of wavelength and intensity resembling the human perception of color identification. For better reasoning refer fig.3.

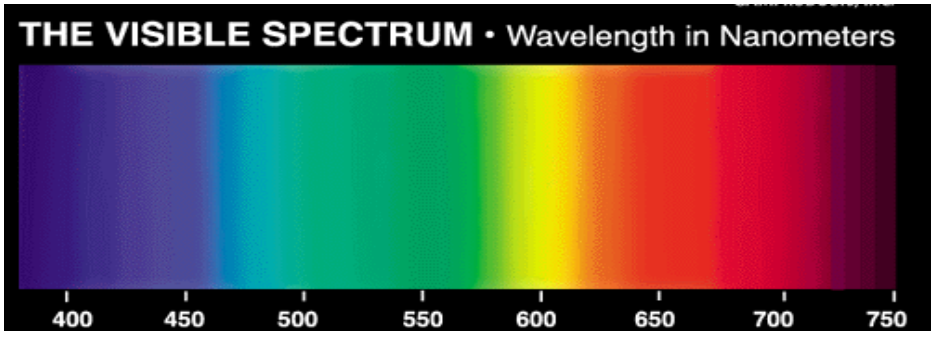

Figure 2. Visible color spectrum []

4. COLOR SYSTEM:

The semiconductor color sensor **PD153** is an element of PN- junctions (photodiodes) with vertically incorporated into substrate. When a monochromatic light source of incident on an object whose wavelength is to be measured, the ray gets reflected and strikes to the semiconductor color sensor. It is shown in fig.3.When ray strikes the sensor it is given to the signal conditioning circuit. This is given to Fuzzy Interface System via PIC microcontroller.

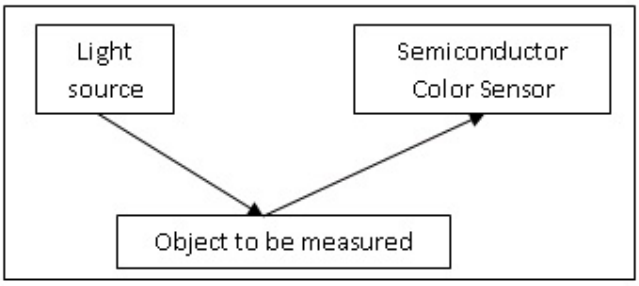

Figure 3. Reflective type color measurement of an object

5. FUZZY MODEL FOR COLOR DETECTION

5.1. FUZZY INFERENCE SYSTEM (FIS)

Fuzzy inference is the process of formulating the mapping from a given input to an output using Fuzzy Logic. Here the two input variables and one output are considered for developing Fuzzy Model for Color Identification. The wavelength in nanometer (nm) and intensity in KJ/mole and output is the degree to the each color forms the variables for FIS. This modeling has been done by using Takagi-Sugeno-Kang's (TSK) method of reasoning.Table-Ishows the values of wavelength, intensity and their corresponding degrees which are given to the ANFIS of MATLAB.

Table 1. Wavelength, intensity and corresponding degrees of color

	Wave-length nm	Intensity kJ/mol	Degree %			Wave-length nm	Intensity kJ/mol	Degree %
	380	326.8	100			530	234.31	100
	388	320.06	80			540	229.97	80
VIOLET	396	313.6	60		GREEN	550	225.79	60
	404	307.39	40			560	221.76	40
	412	301.42	20			570	217.87	20
	420	295.68	100			580	214.11	100
	430	288.8	80			588	211.2	80
INDEGO	440	282.24	60		YELLOW	596	208.36	60
	450	275.97	40			604	205.6	40
	460	269.97	20			612	202.92	20
	470	264.22	100			620	200	100
	482	257.65	80			636	195.26	80
BLUE	494	251.39	60		ORANGE	652	190.47	60
	506	245.43	40			668	185.91	40
	518	239.74	20			684	181.56	20
					RED	700	177.41	100

6. FIS CREATION

6.1. RULE BASE FOR REASONING

The rule base is the kernel of fuzzy inference. For the sake of simplicity the rules are converted into table form. Table-II and Table-III shows the various rules for the inference system. The Number of variables, N = 9 and Rule base matrix is square Number of fuzzy sets used for *wavelength* and *intensity* are same and this gives rise to a square matrix rule base. The outputs of rules are the 81membership functions. Same term set of labels for both wavelength and intensity has been used which are as follows-

Term set for wavelength $=$ { VVL, VL, L, NL, M, NH, H, VH, VVH }, Number labels, N $= 9$
VVL $=$ Very Very Low, VL $=$ Very Low, L $=$ Low, NL $=$ Near to Low,
M $=$ Medium, NH $=$ Near to High, H $=$ High, VH $=$ Very High,
VVH $=$ Very Very High.

Term set for intensity $=$ { VVS, VS, S, NS, M, NB, B, VB, VVB }. Number labels N $= 9$
VVL $=$ Very Very Small, VS $=$ Very Small, S $=$ Small, NS $=$ Near to Small,
M $=$ Middle, NB $=$ Near to Big, B $=$ Big, VB $=$ Very Big,
VVB $=$ Very Very Big

In Row: $1 =$ VVL, $2 =$ VL, $3 =$ L, $4 =$ NL, $5 =$ M,
$6 =$ NH, $7 =$ H, $8 =$ VH, $9 =$ VVH

In Column: $1 =$ VVS, $2 =$ VS, $3 =$ S, $4 =$ NS, $5 =$ M,
$6 =$ NB, $7 =$ B, $8 =$ VB, $9 =$ VVB

The consequent part of rule fired is given as follows-

$$Output1mf\boldsymbol{n} = (r, c)$$

There are two sets of rules: one corresponding to Intensity and other to Wavelength.

The format of fuzzy rule for wavelength to intensity is -
IF intensity is 'r' and wavelength is 'c' THEN $Output1mf\ \boldsymbol{n} = (((r-1) \times 9)c)$

The format of fuzzy rule for intensity to wavelength is -
IF is wavelength 'r' and intensity is 'c' THEN $Output1mf\ \boldsymbol{n} = (((c-1) \times 9)\, r)$

The two sets of fuzzy inference rules are enlisted in table-2 and 3.

Table 2. Fuzzy rule table for color(Intensity)

Wavelength Verseus Intensity	
Row No. (r)	Column out1mfn (c=9)
1	c
2	9+c
3	18+c
4	27+c
5	36+c
6	45+c
7	54+c
8	63+c
9	72+c

Table 3. Fuzzy rule table for color(wavelength)

Inensity Verseus Wavelength	
Column No. (c)	Row out1mfn (r =9)
1	r
2	9+r
3	18+r
4	27+r
5	36+r
6	45+r
7	54+r
8	63+r
9	72+r

6.2 DECLARATION AND COMPUTATION OF MEMBERSHIP FUNCTIONS

For this system there are two inputs: one is wavelength and other is the intensity of color. The range of wavelength is from 380nm to 700nm, while that for intensity is 171 KJ/molto 325KJ/mol. The output is the degree of each color having maximum of 100% to minimum 20%.

Figure 3 shows the FIS-editor window for designing a FIS for color identification.

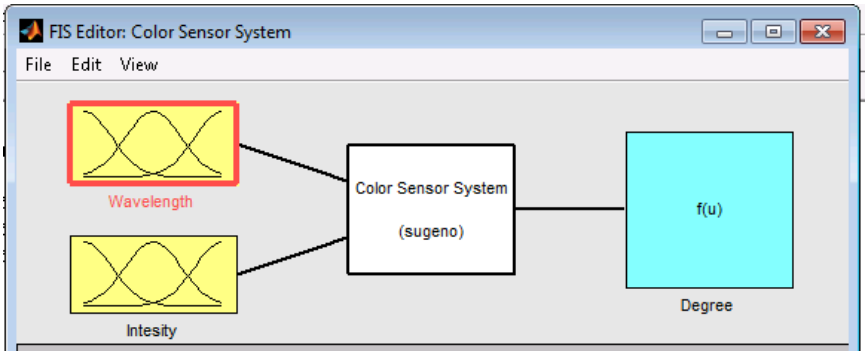

Figure 4. Membership Function Editor for color system

Similarly, fig.5 shows membership function-editor window for input variable *intensity*. The various parameter ranges for intensity are as follows:

$$\mu_{VVS} = L\,(151.8\ 171\ 190.3)$$
$$\mu_{VS} = \Lambda(171\ 190.3\ 209.5)$$
$$\mu_{S} = \Lambda(190.3\ 209.5\ 228.7)$$

$$\mu_{NS} = \Lambda\,(209.5\ 228.7\ 248)$$
$$\mu_{M} = \Lambda\,(228.7\ 248\ 267.2)$$
$$\mu_{NB} = \Lambda\,(248\ 267.2\ 286.5)$$
$$\mu_{B} = \Lambda(267.2\ 286.5\ 305.8)$$
$$\mu_{VB} = \Lambda(286.5\ 305.8\ 325)$$
$$\mu_{VVB} = \Gamma(305.8\ 325\ 344.3)$$

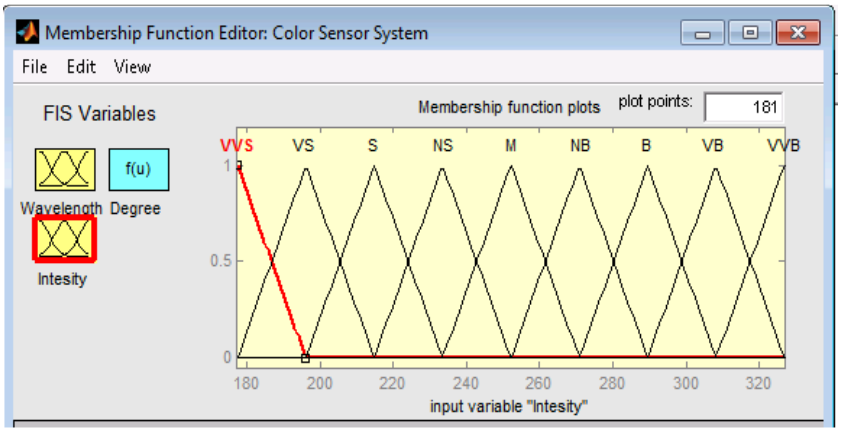

Figure 5. Fuzzy membership function editor window for wavelength

The output can be achieved by training the input data. The training of the membership function parameters is done to emulate the training data. The training process stops whenever the maximum epoch number is reached or the training error goal is achieved. Fig.6 shows the membership function-editor window which are the membership function in linear equation form and referred as *Out1mf1, Out1mf2, Out1mf3 up to Out1mf81*.

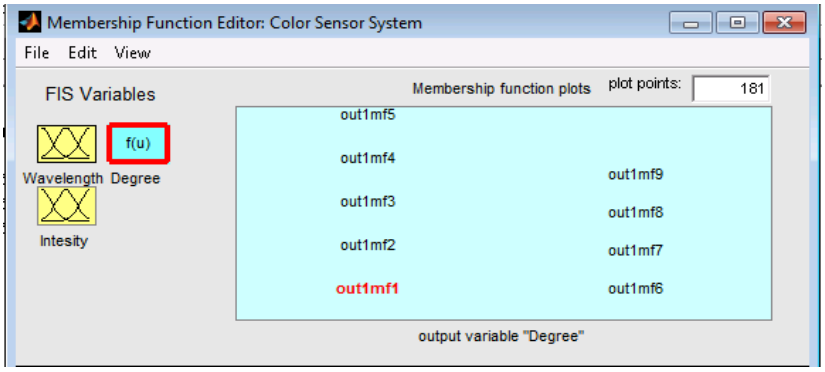

Figure 6. Fuzzy membership function editor window for Degree

The trained data gives the output of the system. That means it gives the degrees for various range of color wavelength and intensity. This output can be checked on the rule viewer.Fig.7 shows the rule viewer window.

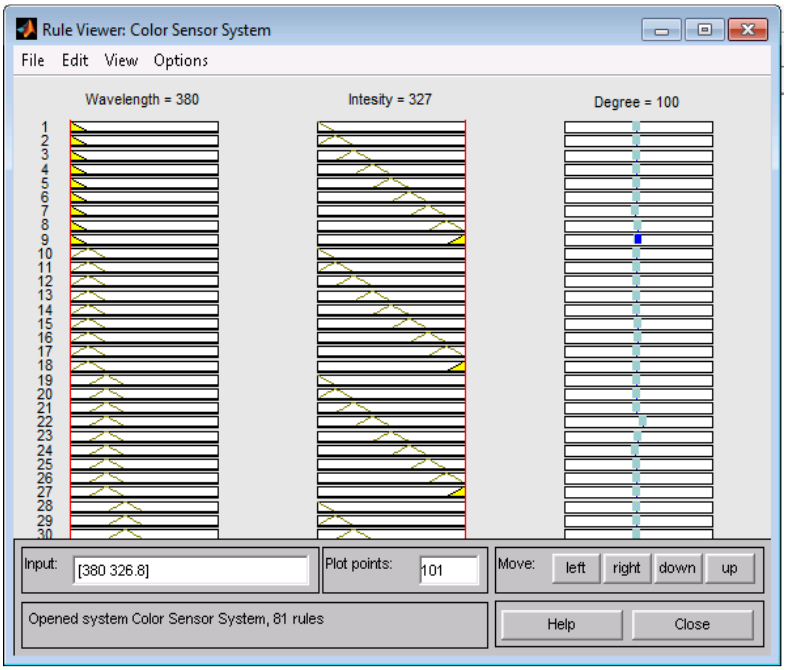

Figure 8. Fuzzy rule viewer window for color sensor system

7. RESULTS AND CONCLUSION:

The wavelength and intensity are inversely proportional to each other. The relation between wavelength and intensity is non-linear. When visible spectrum is scanned across from one color to other effective brightness of color varies as function of wavelength. In other wards there a gradual change in the intensity (shade of color) across the spectrum of color. This can be indicated by degree of percentage. The experimental observations are plotted are shown in the figure 9.

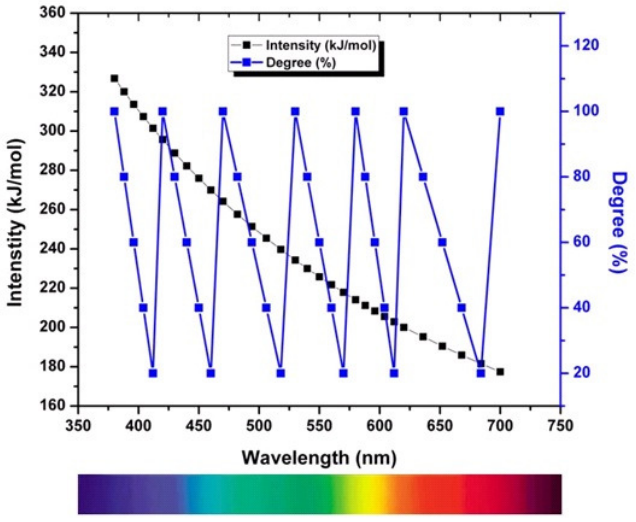

Figure 9. Observed degrees of color by FIS of Color Sensor System

It reveals that the dependency between the intensity and wavelength of color is non linear in nature. Also we could see the saw-tooth variation in the degrees for color when moved from one color to adjacent color across the visible color spectrum. We anticipate the use of observations generated by FIS the where there exists an uncertainty in the color identification. By computing the degrees associated with color we hope uncertainty and ambiguity involved in the color identification can be removed which is highly desirable for color matching in many kind of applications. The uncertainty involved in the color identification has been modeled by membership function used to define the fuzzy sets and the fuzzy inference rules.

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Authors

Dr. R. R. Mudholkar received the M.Sc. degree in 1984 form Karnataka University, Dharwad, M.Phil. in 1996, Ph.D. degree in 2003 from Shivaji University, Kolhapur. He is Associate Professor in Electronics Department, Shivaji University, Kolhapur. His total teaching experience is 24 years. He has worked as a Resource Person at various workshops and conferences. He has attended more than 25 National and Internal national Conferences. He has published more than 35 papers in journals and conferences. His current research interest lies in Fuzzy Logic, Neural Network, Fuzzy Systems, and Cloud Commuting. Two students have completed Ph.D. and two M.Tech. Degrees and presently he is guiding to 7 Research Students.

Snehalata T. Patil received the BSc degree in Electronic science from the Shivaji University Kolhapur, India; currently he is MSc student in Electronics Science from Shivaji University Kolhapur, India. She has worked under supervision of Dr. R. R. Mudholkar; His research interests include Fuzzy Logic, Artificial Neural Network, Power Electronics, Embedded Systems.