2016 13th International Conference on Electrical Engineering, Computing Science and Automatic Control (CCE), Mexico, City. Mexico. September 26-30, 2016.

Fuzzy Inference System for Region Segmentation Using the YCbCr Color Model

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Abstract — **Segmentation is one of the main tasks in image processing and pattern recognition systems. In this paper, a segmentation technique of color images based on fuzzy inference model is proposed. Triangular membership functions are used in the input of the fuzzy system, the Mamdani type fuzzy inference system is applied and for the output universe, singleton-type functions are used. To get the accurate output value, the weighted average method is applied. The YCbCr color space is used as feature space. The fuzzy membership functions characterize the different membership levels between hue and Chroma from the YCbCr color model. The fuzzy inference system classifies data and generates regions of pixels with an homogeneous color level in the output images. The proposed technique was also applied to the RGB color space and the results were compared; the best results were obtained in the YCbCr color space. In this color model, the changes of hue in presence of illumination variations are considered, so that it has a better performance in the segmentation task; in addition, the processing time was lower in this color space.**

Keywords — **Fuzzy logic, fuzzy set, fuzzy rules, color model, segmentation, chrominance and luminance.**

I. Introduction

Color perception begins by a chromatic light source, which is an electromagnetic radiation, with wavelengths between 400 and 700 nm approximately. Part of the radiation, which is reflected on the surface of objects, is a scene and the resulting reflected light reaching the human eye, generates the feeling of color perception [1-4].

Brightness is the luminance or relative darkness of the color, on the other hand, hue is the color reflected or transmitted through an object, saturation (also called chroma) represents the contribution of white color existing in proportion to the hue, or more precisely, the color purity [2]. This is the basis of YCbCr color space.

The color segmentation in the computer vision field is important for pattern recognition and image processing tasks. Segmentation is the process of partitioning an image into regions of interest (sets of pixels), with homogeneous features. They can share one or more of those characteristics, such as shape, color, texture, lighting, etc.

The color of the shapes within an image can be used to simplify the identification and extraction of the regions of interest and can be recognized as separate objects.

Image segmentation methods have recently been proposed, many of them based on Neural Systems and Fuzzy Logic. A segmentation system based on neural networks has been proposed by G. Dong *et al* [5], they performed a modification of the Luv color space and with the new data, a self-organizing map-type (SOM) neural system was trained. The main problem of his work is the high computational cost because of, at first, the transformation of data from RGB color space to XYZ color space; secondly, the obtention of the Luv modified space, and finally training, for each image, the SOM.

The most widely used method to improve the execution times of the segmentation algorithm is the multi-resolution pyramid, which is used to obtain low resolution images to apply segmentation (by SOM or Fuzzy C-Mean.) and the resulted data is extrapolated to the original resolution [6,7].

Different proposals have been presented for the image segmentation using fuzzy logic by modifying the classical algorithm of Fuzzy C-Means (FCM) [8-10]. In [8] the FCM objective function was modified and the gamma factor (γ) was introduced. With this factor, the effect of intensity changes of the pixels in a neighborhood was controlled, obtaining the noise image segmentation; the calculation of the gamma factor for different images and different window sizes is one of the drawbacks of this proposition. In [11] a segmentation approach using Takagi-Sujeno (TS) fuzzy model was proposed; the system was applied on the HSV color space to determine the parameters of skin color. The H and S components were used to establish de color and V, the illumination component, was not considered because the work was developed in a light controlled environment. This work is supported by a similar idea, the two components of Croma, Cb and Cr, are used to establish de color and owing to the fact that the proposed system will work in an environment with illumination changes, the third component Y is considered in the fuzzy inference system. Triangular membership functions in the input of the system and the Mamdani-type inference are used, singleton-type functions are used on the output, the accurate output value is obtained by the weighted average method. Distribution of membership functions for classification of hue is made on the Cb and Cr components of YCbCr color space (see Fig. 1).

This paper is organized as follows. In Section II, it is given a brief introduction to the YCbCr color space. The basis of fuzzy logic is discussed in section III. Section IV presents the fuzzy rules used by the system. The application of segmentation system is presented in Section V. The discussion of the results is made in Section VI. Section VII presents the conclusions.

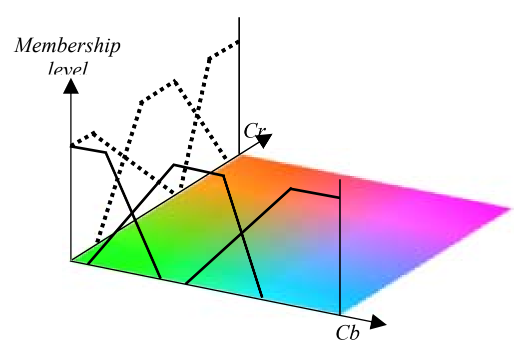

Fig. 1 Distribution of membership functions in the space of chroma Cb and Cr.

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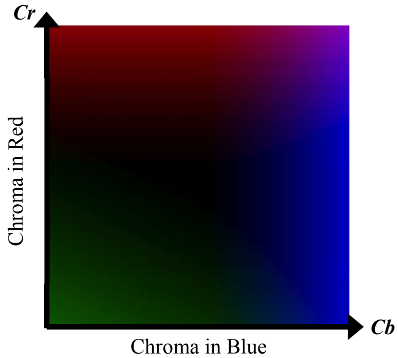
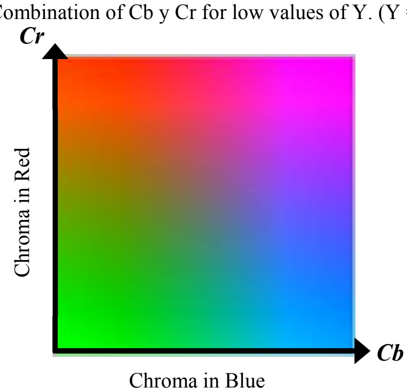
II. YCbCr COLOR MODEL

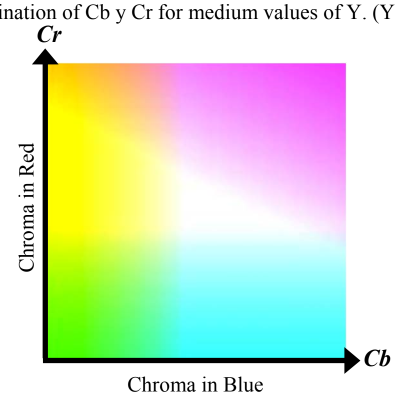
It is a nonlinear encoding of RGB color model. The YCbCr model components determine the luminance and chrominance. "Y" is the contribution of light in the pixel; "Cb and Cr" are the blue and red chrominance components, respectively. The combination of Chroma values are different colors (color coordinate system), but the luminance value "Y" determines the brilliance of color, specifically, for low values of "Y" the colors will be dark; otherwise, the colors will look very bright with the hue close to white. The three cases for the variation of illumination "Y" are shown in Fig. 2, as can be seen, the color coordinate system changes its hue.



(a) Combination of Cb y Cr for low values of Y. (Y = 10).



(b) Combination of Cb y Cr for medium values of Y. (Y = 128).



(c) Combination of Cb y Cr for high values of Y. (Y =240).

Fig.. 2. Color coordinate system obtained by combination of Chroma. Value of low illumination (a), value of medium illumination (b), value of high illumination (c).

III. FUZZY LOGIC

In the YCbCr color space, the transition between a color and another one does not have a defined borderline namely, it changes gradually from a hue to another. Due to the fact that fuzzy systems work with uncertain data, this system is very appropriate.

A fuzzy set is associated with a linguistic value that is defined by a word, an adjective or a linguistic label.

In the fuzzy sets, the membership function can take values in the interval (0, 1), making a gradual transition between zero and one. Not an instantaneous one, such as in classical sets.

The fuzzy set in a universe set can be defined as shown in (1).

$$color = \{(x, \mu_{color}(x)) | x \in U\} \qquad (1)$$

Where µColor (x) is the membership function of the variable x, U is the universe set. The closer the Color of the set membership to the 1 value, the greater the variable x belonging to the set *Color* will be, as shown in Fig. 3.

Equation (2) is a trapezoidal fuzzy set type (see Fig. 3) which describes the different membership levels [12]. As a fuzzy set, it can be inferred that the maximum level of membership is equal to one, the slope of a line determines the different membership levels and the nonmembership is equal to zero. For this system the overlap in the fuzzy sets describes the inaccurate transition between the hues, as detailed in Fig.4.

$$\mu(x) \begin{cases} 0 & if\ x \leq a \\ x-a/b-c & if\ a \leq x < b \\ 1 & if\ b \leq x < c \\ d-x/d-c & if\ c \leq x < d \\ 0 & if\ x \leq a \end{cases} \qquad (2)$$

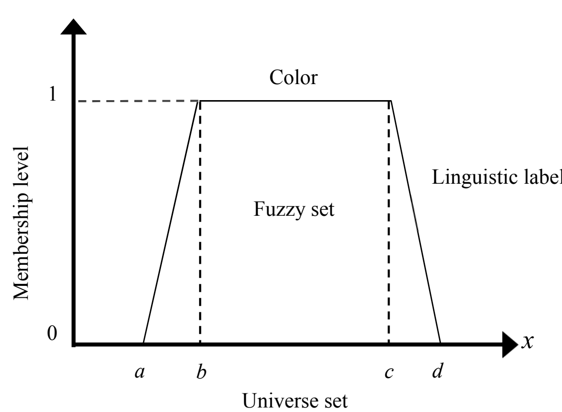


Fig. 3. Trapezoidal fuzzy set.

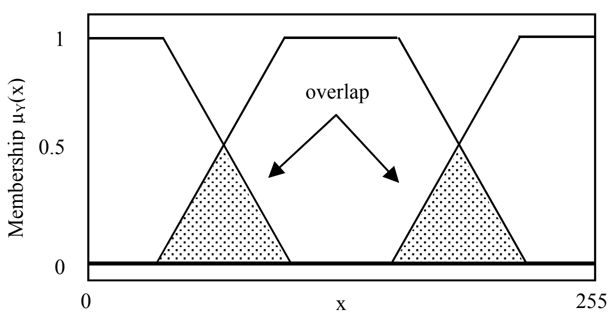


Fig.4. Overlap in fuzzy sets, inaccurate transition of the hue.

IV. Fuzzy Rules

A fuzzy inference system uses the expert knowledge to generate the understanding base, which will give the system the ability to make decisions. This knowledge base is modeled by creating a rule set, which generates the system output; in this case, it is the membership of pixels within an image above to a set or another.

As mentioned, the component "Y" represents the contribution of light existing in a color, in Figure 5 it can be seen a graphical diagram of the inference of nine fuzzy rules when the colors are considered dark (low light).

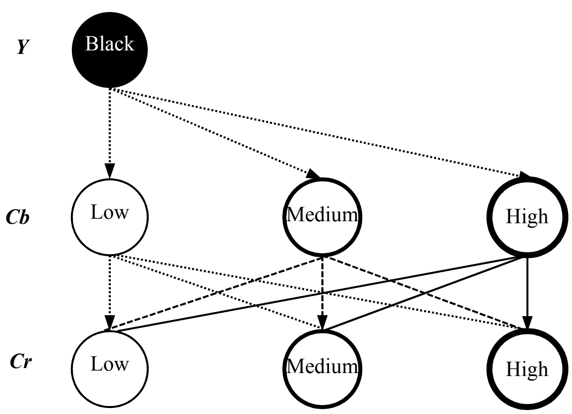


Fig. 5. Graphic description of the fuzzy rules.

It has been chosen twenty-seven possible combinations, which are shown in table I.

To generate the output image (segmented regions), the triad of values Y, Cb, Cr, for each pixel in the input image is presented to the fuzzy inference system. The centroid defuzzification method is used to determine the output value [12, 13]. It is given by the algebraic expression (3).

$$Output = \frac{\sum_{i=0}^{n} \mu(A)_i \cdot A_i}{\sum_{i=0}^{n} \mu(A)_i} \qquad (3)$$

Where Σ denotes an algebraic sum and A represents the different colors expected at the output, see Table I.

TABLE I
COMBINATIONS THAT GENERATE THE BASE OF FUZZY RULES.

No. Rule	Description Y	Cb	Cr	Output
1	Black	Low	Low	Black
2	Black	Low	Medium	Black
3	Black	Low	High	Black
4	Black	Medium	Low	Black
5	Black	Medium	Medium	Black
6	Black	Medium	High	Black
7	Black	High	Low	Black
8	Black	High	Medium	Black
9	Black	High	High	Black
10	Color	Low	Low	Green
11	Color	Low	Medium	Yellow
12	Color	Low	High	Red
13	Color	Medium	Low	Cyan
14	Color	Medium	Medium	Gray
15	Color	Medium	High	Crimson
16	Color	High	Low	Blue
17	Color	High	Medium	Violet
18	Color	High	High	Magenta
19	White	Low	Low	White
20	White	Low	Medium	White
21	White	Low	High	White
22	White	Medium	Low	White
23	White	Medium	Medium	White
24	White	Medium	High	White
25	White	High	Low	White
26	White	High	Medium	White
27	White	High	High	White

V. Segmentation of Hue Using Fuzzy Logic

The YCbCr color space has a color chart consisting of the combination of the Chroma belonging to the red and blue (Cb and Cr) and different levels of luminance (Y), see Fig. 2.

For the universe set *"luminance"*, are considered three linguistic labels, *"Black"* which represents the low contribution of light, *"Color"* where it is considered the optimal lighting to perceive the tone of a color, and *"White"* representing a high contribution of light, see Fig. 6.

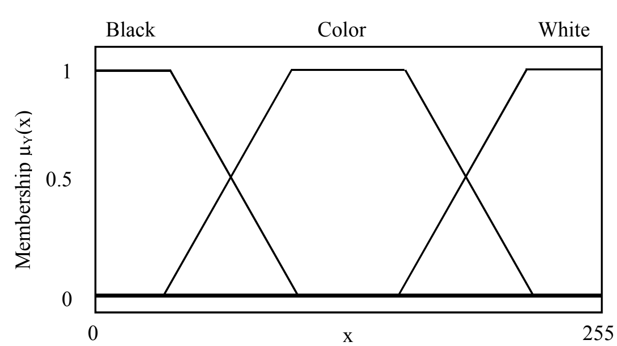
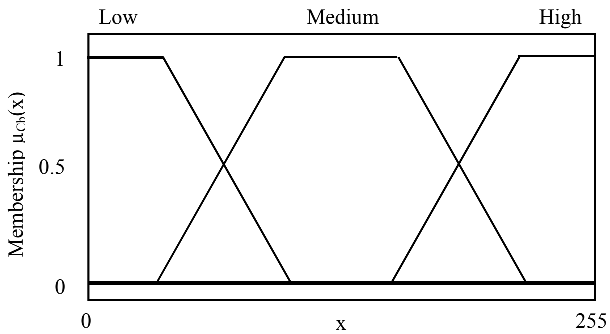


Fig. 6. Fuzzy sets for the universe set. *"Luminance";* Y

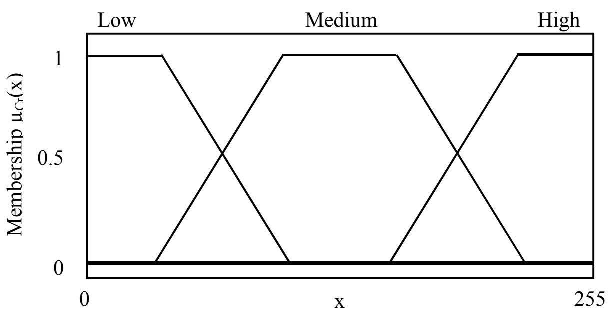
In order to reach the perception of color, the presence of luminance will be necessary without reaching saturation.

Different combinations of the components "Cb and Cr" typify the color, taking this into account; the fuzzy sets are generated by their combination representing the different colors that the system can classify.

Three fuzzy sets are defined, each one with their linguistic label respectively for each Chroma component. *"Low"*, if the Chroma saturation in blue or red is low, *"medium"* if the Chroma saturation is medium, and *"high"* if the Chroma saturation is high as detailed in Fig. 7.



(a) Fuzzy sets for blue chrominance, Cb.



(b) Fuzzy sets for red chrominance, Cr.

Fig. 7. Fuzzy sets of chrominance. (a) Blue chrominance *Cb*, (b) Red chrominance *Cr*.

The values ⟨*a, b, c, d*⟩, which are parameters of (2), represent the form of all the fuzzy sets in a universe set (see Fig. 8). By varying these parameters, different slopes in the boundary lines of the fuzzy sets are generated, modifying the zone that represents the uncertainty data.

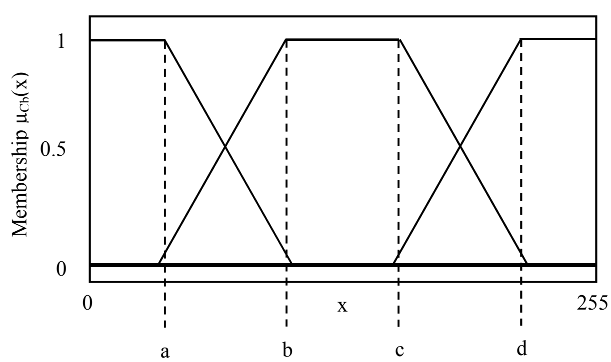


Fig. 8. Parameters for controlling the distribution of the fuzzy sets <a, b, c, d>.

Also, it is possible to find a particular hue value by modifying these parameters, for example, if the red color and its different hue values are sought (the red color region is in the upper left corner in color palette as shown in Figure 8) it is necessary to expand the region covered by the "Low" set in "Cb" and the "High" set in "Cr", which means that the value of the parameter "a" in "Cb" should be increased and the value of the parameter "d" in "Cr" should be decrease. The region of interest is then amplified as shown in Fig. 9.

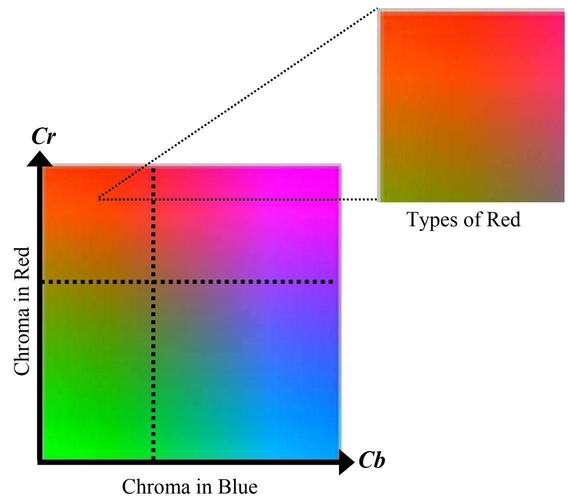


Fig. 9. Color model YCbCr. Search of red in the color palette of the chrominance (Cb and Cr)

The numerical values of ⟨*a, b, c, d*⟩ parameters, which are employed in the fuzzy sets for red segmentation, are shown in Table II.

TABLE II

VALUES OF THE PARAMETERS ⟨*a, b, c, d*⟩ FOR THE FUZZY SETS OF Y, CB Y CR

	Y	**Cb**	**Cr**
a	30	95	85
b	60	105	95
c	200	195	145
d	235	205	155

One of the images tested with the proposed fuzzy inference system is shown in Fig. 10, which contains an orange object, a single pixel of the object has the following values:

Y	Cb	Cr
143	94	188

The membership values obtained by processing the pixel described above are shown in Table III.

TABLE III
MEMBERSHIP VALUE FOR EACH FUZZY SETS

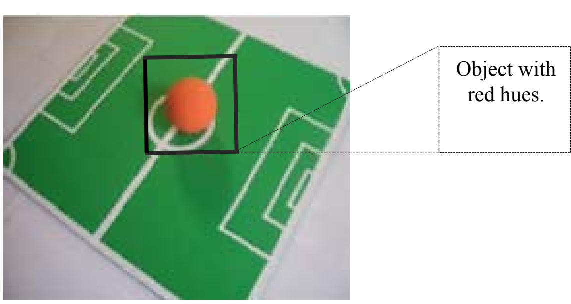
Fuzzy Sets µ	Membership Value
μ_{BlackY}	0
μ_{ColorY}	1
μ_{WhiteY}	0
μ_{LowCb}	1
$\mu_{MediumCb}$	0
μ_{HighCb}	0
μ_{LowCr}	0
$\mu_{MediumCr}$	1
μ_{HighCr}	0

The membership values shown in Table III are introduced in (3) to obtain the numerical values of the system output. Variables named “S” represent the output fuzzy sets (fuzzy Sigleton’s), each of them are located at the expected output value, for example, S10 represents the red color suggesting that the pixel in the output image will have R=255, G=0, B=0 as a numerical values if the numerical value obtained in (3) is similar to S10. Table IV lists the values of all the fuzzy singleton’s.

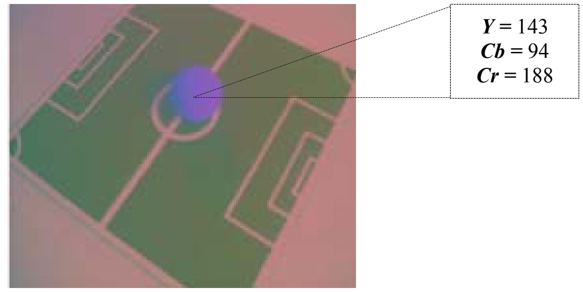
TABLE IV
FUZZY SINGLETON VALUES

	Output Numerical Value
SI	10
S2	33
S3	56
S4	79
S5	102
S6	125
S7	148
S8	171
S9	194
S10	217
S11	240

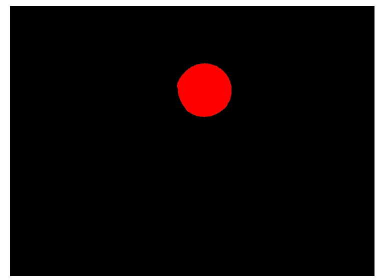
To form the output image, each pixel is processed in the same way. The method used for image processing is shown in Fig. 10, at first the original image is in RGB color space (Fig. 10 (a)), secondly, the image is transform into YCbCr color space (Fig. 10 (b)) and finally, the fuzzy inference system is applied to the result image (Fig. 10 (c)). It is worth noting here that the output singletons sets are represented again in RGB color space to be displayed on screen.



(a) RGB color space image showing the segmentation area.



(b) YCbCr color space image. Choosing a point to be processed.



(c) Output image obtained by segmentation system.

Fig. 10. Graphic sequence of the fuzzy segmentation system (a), (b), (c).

VI. Experimental Evaluation

To evaluate the effectiveness of the segmentation system by fuzzy logic, the segmentation of the green hue existing in the original image of Fig. 10 (a) was proposed. This photo was taken in the laboratory, in a closed room, under semi-controlled lighting conditions. The changes in illumination inside the photo can be noticed. The image contains a green area that simulates the conditions of a (small) soccer field, a red ball and white lines that define the green area. This particular photo was chosen because the given segmentation system will be a part of the vision system of a robotic prototype that serves as a football player.

With the system, was performed the segmentation using two color spaces, RGB and YCbCr, in order to compare execution times.

The code was developed based on Matlab programming language in its version R2010a, on a computer with an Intel Core2 Duo T6400 2 GHz processor. Images were obtained with a Kodak EasyShare CD14 with a resolution of 1280x960, JPG format.

The execution time of the segmentation system by using RGB color space was 2 min.15 sec. and for YCbCr color space was 1 min. 75 sec.

The difference between RGB and YCbCr execution times is mainly due to the fact that, in the RGB color space, each component contributes to obtain a color hue so that the three components are an input of the fuzzy system; for YCbCr, the component "Y" determined, as a first step, if the pixel has low lighting (black), high lighting (white) or if the lighting is good enough to perceive the hue of a color, the pixel Chroma components to determine the membership level are discussed only in the latter case.

In Fig. 10 (c) shows the result of the segmentation of the RGB color space.

For segmentation in YCbCr, it is transformed the original image into this color space, due to fact that the image is in RGB color space, Fig. 10 (a), the rgb2ycbcr function was used for this purpose, which is part of the "image processing" toolbox of Matlab, (see Fig. 10 (b)). In Fig. 10 (d) the result of segmentation can be observed.

The changes in hue due to the variation of lighting was considered in the YCbCr color space, so that, when the images in Fig. 10 (c) and Fig. 10 (d) were compared, as expected, it is observed a better performance of the segmentation system in YCbCr.

The variation of lighting is not considered for the RGB, so that, the pixels in the top center of the image Fig. 10 (c), were classified as non-green hue.

In Fig. 10 (a), can be seen three main regions, one of them is the green region (region of interest), and two more regions that are covered by yellow and gray pixels. The last two regions are the result of the membership levels to the fuzzy sets of the remaining pixels.

The values of the parameters ⟨a, b, c, d⟩ of the fuzzy sets which are used for the segmentation of green color in YCbCr are shown in Table V.

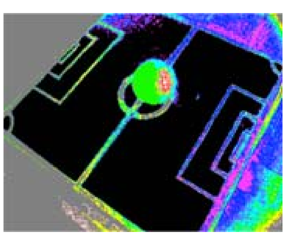
TABLE V

VALUES OF THE PARAMETERS *⟨a, b, c, d⟩* FOR THE FUZZY SETS OF Y, CB Y CR

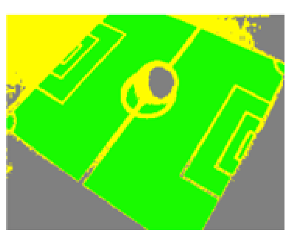
	Y	Cb	Cr
a	30	95	85
b	60	105	95
c	200	195	215
d	235	205	225

(a) RGB color model

(b) YCbCr color model



(c) RGB output image



(d) YCbCr output image

Fig. 10. Segmentation process in the RGB and YCbCr color spaces, (a) Original image in RGB color space, (b) Original image transformation into YCbCr color space, (c) Segmentation of green color in RGB, (d) Segmentation of green color in YCbCr.

Another important point to mention is that the equations to conform the fuzzy sets are relatively simple and only require 4 parameters to generate the fuzzy sets that cover a universe set. It was taken advantage of this simplicity and it was implemented in a segmentation system in an FPGA.

VI. Conclusions and Future Works

This paper proposes an application of segmentation of regions in images using fuzzy logic. It exploits the ability of fuzzy sets for modeling accurate data to interpret the transition from one hue to another by using the blue and red chromas in the YCbCr color space. Trapezoidal sets are proposed for mapping of the chroma to membership levels.

MATLAB programming language was used in its version R2010A to develop the system and was applied in two color spaces, RGB and YCbCr, execution times were 2 min. 1 min 15 sec and 75 sec. respectively.

Due to fact that the simplicity of the formulas that are used to develop the fuzzy inference system, the implementation in hardware is feasible. In the laboratory it has been implemented the proposed system, using the Spartan 3E development board which contains an FPGA xc3s500e from XILINX Company. The proposed segmentation system has been applied in the object tracking and orientation of robot using brands.

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