FPGA based Fuzzy Optoelectronic Color Sensor System

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ABSTRACT
This paper describes the designing and implementation of a novel Fuzzy Optoelectronic Color Sensor System. It is based on a Light-Dependent Resistance (LDR) as cheap light sensor and a smart signal processing Fuzzy Logic Algorithm (FLA) implemented on a Field Programmable Gate Array (FPGA). In order to perform suitable and reliable color identification a fuzzy model has been used, which manages the task complexity easily. The system performance has been investigated in terms of failure probability in recognizing color samples and results obtained demonstrated the effectiveness, reliability and robustness of the implemented Fuzzy Logic Algorithm for color sensing.

General Terms
Fuzzy color sensor, fuzzy hardware implementation.

Keywords
Fuzzy, FPGA, Color, Handel-C, LDR, Optoelectronic.

1. INTRODUCTION
The fuzzy logic in broad sense encompasses Fuzzy Sets, Fuzzy Reasoning and Fuzzy Relation from standpoint of Industrial applications. Its main objective is to model complex, non linear dependency that exit between input and output variables of a system. Further it aims to represent system operation knowledge in the form of linguistic rules .Fuzzy logic is simply a technique that mimics the human reasoning. This technology is now being explored in wide domain of applications. In the present investigation the Fuzzy Logic has been incorporated in color sensing system. Unlike vision sensors that are designed for pattern detection, contour verification, or edge location, the full color sensors are aimed only at a specific spot on the target that verifies the right quality of product or the presence of desirable attributes of object under test. This allows the sensor to operate at speeds as fast as 1 ms, which is much faster than the typical 20 ms update time required by vision sensors [1]. Several researchers use LDR as color sensor along with RGB LED as reference light source. But they have some limitations that only two or three complete color readings can be performed per second [2, 3].

Human eyes are more sensitive to the visible colors than reading numerical values associated with (say) physical parameters. Especially, if there are number of readings displayed at a time on a single frame of VGA Display, it becomes complicated task for a plant supervisor to make a decision about such values and compare it with observed colors. Considering this fact, the system has been designed and developed, which is capable to display object color on VGA monitor. A Soft IP Core developed in Handel-C comprises of different entities, like Fuzzification, Defuzzification, Horizontal and Vertical Synchronization pulses required driving a VGA monitor etc. The Fuzzy Logic Color System presented here is implemented on FPGA that can determine color with a cost effective as well as with reasonable accuracy and precision. A conventional sensor could fail to perform this function because it uses a very precise set of rules to eliminate environmental interference.

2. FUZZY LOGIC COLOR SENSOR
The light dependent resistor (LDR) is a sensor whose resistance decreases when light impinges on it. Here the color sensor consists of LDR along with a white light emitter. The relative resistance of LDR is recorded for basic colors by illuminating object using white light emitter. The relative response of LDR for color is considered to figure out the actual color of the object. The exterior of the sensor is covered in black insulating cat to cut out all ambient light from interfering with the LDR as shown in Fig.1. This is important, as ambient light can wreak havoc on the readings. The LDR is connected with a 47k resistance, to divide the reference voltage (5V) between itself and the fixed resistor. Table 1 shows the relative response of LDR which is nonlinear and hence fuzzy logic can be suitable here to find out object color based on the relative resistance of LDR. A knowledge-based analysis is described which uses Fuzzy Logic to analyze the colors based on relative response of LDR. The design of Fuzzy Logic Color Sensor aims to achieve precise color sensing ability, while maintaining the expected simplicity of operation and durability of typical discrete industrial sensors. Several other key goals must be considered in system design such as high speed, re-configurability, high repeatability, and long life of light source

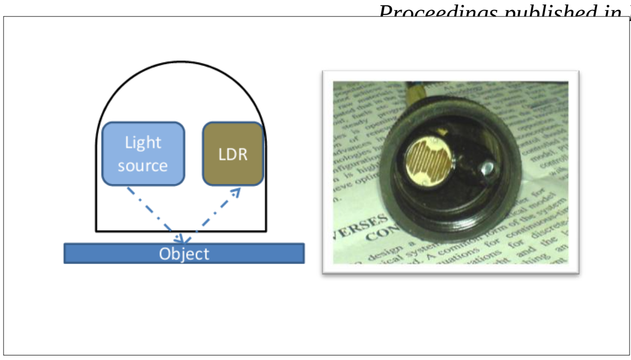


Fig 1: Setup of LDR as Color Sensor

Table 1. Table Type Styles

Color	Relative Resistance (K.ohm)
Red	72
Yellow	21
Green	55
Cyan	20
Blue	79
Magenta	45
Black	481

3. INTERFACING DETAILS

The schematic shown in Fig.2 describes the interfacing of ADC0804 with voltage divider network made up of LDR and 47k resistor. Three resistor networks are used to drive Red, Green and Blue lines of a VGA Monitor that are wired around the Cyclone-II FPGA. Soft IP Core has been developed and implemented in FPGA, which acquires the digital data from ADC corresponding to the voltage across LDR. In order to display color of an object under test, a look up table has been used. FPGA produces three sets of 4-bit signals for the color on VGA monitor i.e. Red, Green and Blue. Each of the color signals is the sum up of currents drawn from the output of a 4-bit variable resistor type DAC.

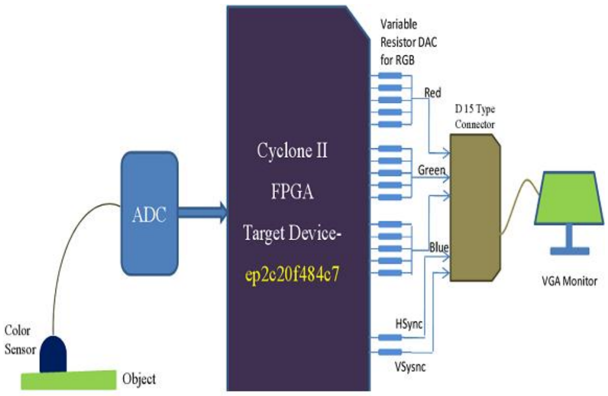


Fig 2: Schematic of Fuzzy Optoelectronic Color Sensor System

4. FUZZY LOGIC ALGORITHM

Fuzzy Logic Algorithm (FLA) calculates the wavelength of object color in the form of Fuzzy Relation. The fundamental nature of Fuzzy Control Algorithm is the conditional statement between fuzzy input variable (resistance of LDR) and fuzzy output variable (wavelength of color). A Fuzzy Logic Algorithm consist three-parts: fuzzification of input, defuzification of output, and Knowledge representation in the form of IF-THEN rules. Fuzzification is the process of changing a real scalar value into a fuzzy value. Fuzzy variables are used to translate real values into fuzzy values. Input variable to the FLA is the resistance of LDR. Triangular shape membership functions are used to fuzzify the input. For fuzzifier program, it is necessary to decide the range of fuzzy variables related to the crisp inputs. Fig.3 shows the fuzzy sets of input linguistic variable which are used to partition the LDR resistance range labeled with VS = very small, S = small, M = medium, L = large, VL = very large.

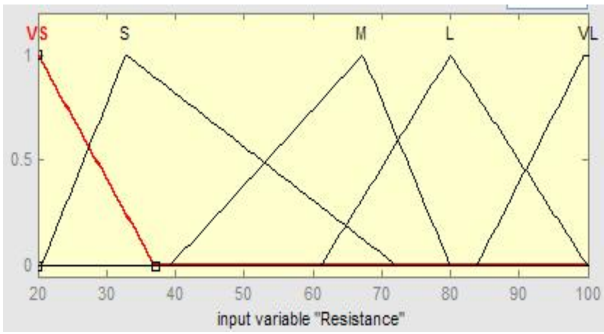


Fig 3: Membership Function for Input Linguistic Variable

In present study typically one output variable has been considered, which nothing but the wavelength of color is. It is necessary to assign fuzzy memberships to output variable similar to the input variable. The fuzzy sets used for wavelength are as follows: VS = very small, S = small, M = medium, L = large, VL = very large. Fig.4 shows the graphical representation of the membership function for output linguistic variable.

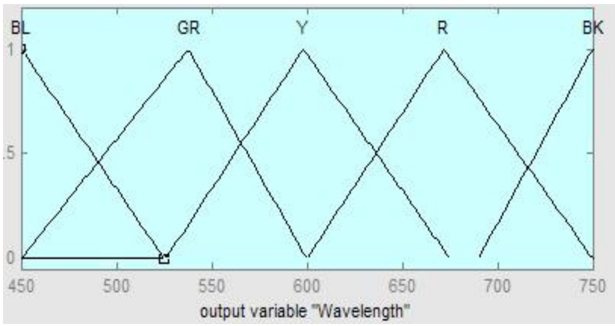


Fig 4: Graphical Representation of the Membership Function for Output Linguistic Variable

Knowledge Representation and Rule block deals with decision making. Once the current values of the input variables are fuzzified, the FLA continues with the phase of 'decision-making' or deciding what will be the wavelength of the color. The rules 'IF' part describes the situation, for which the rules are designed. The 'THEN' part describes the response of the fuzzy system in this situation. The rule policy of FLA is structurally formulated in as shown in Table 2

Table 2. Rule policy of FLA

Rule No.	IF the Resistance is	THEN wavelength is
1	VL	VL
2	VS	M
3	S	VS
4	M	L
5	L	VS

Based on the of Fuzzy Logic Algorithm output i.e. wavelength the lookup table (LUT) is used to display actual object color on a VGA monitor [4]. The LUT is formulated in Table 3.

Table 3. LUT for output RGB color code

Color	Wavelength (nm)	Degree %	Code for RGB color
Blue	470	100	00F
	482	80	04D
	494	60	07A
	506	40	0A7
	518	20	0D4
Green	530	100	0F0
	540	80	0D4
	550	60	0A7
	560	40	07A
	570	20	04D
Yellow	580	100	FF0
	588	80	FF4
	596	60	FF7
	604	40	FFA
	612	20	FFD
Orange	620	100	F90
	636	80	F94
	652	60	F97
	668	40	F9A
	684	20	F9D
Red	700	100	F00

5. DISCUSSION OF DESIGN SYNTHESIS

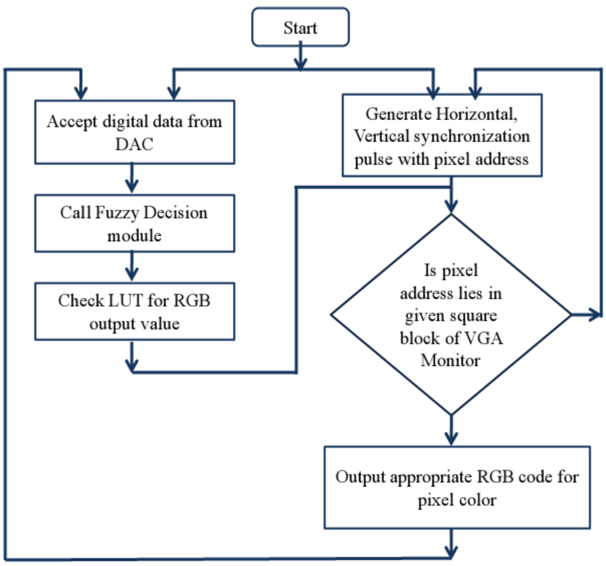


Fig.5. Flow Diagram of Fuzzy Optoelectronic Color Sensor System

The design of Fuzzy Logic Algorithm and its hardware realization forms the core of Fuzzy based Color Sensing System. The FLA designed has been synthesized by using FPGA. In the article [5] we have demonstrated how to synthesis FLA in microcontroller using Embedded-C language. A similar concept is applied in the present work to develop Soft IP Core using Handle-C language. The basic flow chart of the program is shown in Fig.5.

The display resolution of 1024(columns) x 768(rows) has been selected, for which a 25.175 MHz clock is provided at the clock input of the FPGA. The ADC (7:0) input signals accept the data from ADC's output and sends it to Fuzzy Logic Algorithm for further processing. Fuzzy decision making takes 38 clock cycles at 50 MHz system clock. The whole program has been successfully simulated using Handel-C compiler. Fig.7 represents the snapshot of generated HDL file of FLA.

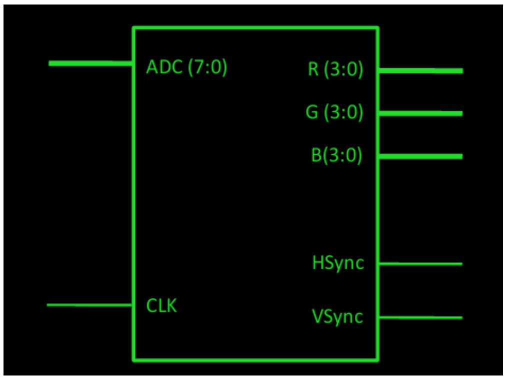


Fig. 6: Top Level RTL View of Fuzzy Optoelectronic Color Sensor System

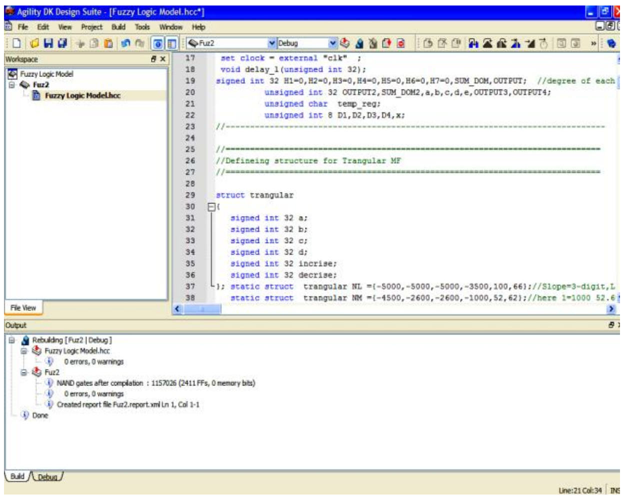
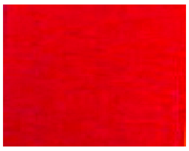
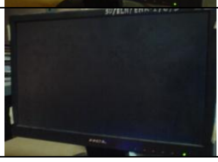


Fig 7: Generated HDL Files of Fuzzy Optoelectronic Color Sensor System

6. RESULT AND CONCLUSIONS

Fuzzy inference system translated by commercially available special software tools are suitable only for a specific hardware and very hard to modify for other platform. At this juncture we have designed and implemented fuzzy inference system in FPGA without using any special software tool. This can save the development cost of the system and can be portable for different hardware platform with minor changes.

Table 4. Different Object Colors Displayed on VGA

Actual Object Color	Object Color Displayed on VGA Monitor
	
	
	
	
	
	
	

The snap shots as shown in Table 4 indicate the different object colors displayed on VGA monitor during testing of system in the laboratory

From the Table 4 it is clear that there is very close agreement between the object colors displayed on VGA by our system and that of actual object color, which validates the color sensing by our system. On other side the decision making of the system has been instantaneous typically 0.6 microseconds due to use of FPGA and single reference light source. It quite faster as compared to color sensing by vision sensor technique. The accuracy of proposes Fuzzy Color Sensor System can be enhanced by incorporating more fuzzy linguistic variable in input and output. The reported development has actually seen helping the different sector. For example to sort candy and put it in a bin based on its color.

In the commercial storage of fruits, vegetables to separate vegetables and fruit according to their color, in Automotive carpet manufacturing to match carpets to vinyl heel pads etc.

7. REFERENCES

[1] Mark Sippel, "Full Color Sensing, SensorTech", June 15, 2011.Avalabel online at http://sensortech.wordpress.com/2011/06/15/full-color-sensing

[2] Michael Gasperi, Color Sensor, Nuts and Volts magazine, 2002. available online at http://www.philohome.com/sensors/colorsensor.htm

[3] David Cook, "Cadmium-Sulfide Color Sensor", Robotic webpage, 2000, Available online http://www.robotroom.com/ColorSensor.html

[4] John December, "Percent Color Codes", 2010. Available online at http://www.december.com/html/spec/colorcodes.html

[5] Nhivekar G.S., et al "Implementation of fuzzy logic control algorithm in embedded microcomputers for dedicated application", International Journal of Engineering, Science and Technology, Vol 3,No 4, pp. 276-283, 2011.

[6] Peter Wilson, "Design Recipes for FPGAs - A Simple VGA Interface", EE Times Design, 2008.Avalabel online at http://www.eetimes.com/design/programmable-logic

[7] Altera, "DE2 User Manual", 2006. Available online at http://www.johnloomis.org/altera/DE2/DE2_UserManual.pdf

[8] Tanaka K., "An Introduction to Fuzzy Logic for Practical Applications", Springer-Verlag, New York, pp 1-119, 1996.