Novel measurement of chromaticity of color ball

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ABSTRACT

In this paper we present a new color measurement technique in which an innovation of a seven color ball sensor to detect the chromaticity of the tested sample was introduced. Developed with the advanced micro-processor, color ratio comparison technique, technique of the optoelectronic detection and multiplexer circuit and software design, this measurement device is capable to perform an accurately stable, high speed and multi color detection by real time measurement. By this arrangement, the seven color balls produce 5040 combinations of color. Compared with traditional spectro-photometer, the color detection error of the system is less than 0.1%. And it can be applied to classify the LED's color luminance and chromaticity.

Keywords: luminance, chromaticity, data comparison

創新之彩色色彩量測

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摘　　要

本研究主要目的在建立七種不同彩色球色彩量測的新色彩多工量測技術。主要技術內容包括色彩比對、多工微處理電路、色彩量測電路與多工色彩辨識程式等。本技術優點量測精度高與速度快，並可即時一次進行多色彩樣品量測。驗證方式係將七種不同顏色彩球，各別置於一圓形排列的七個半圓空穴內，其排列方式共5040種，經測試結果色彩比對誤差小於0.1%，優於一般分光光譜儀僅能做色彩量測，它可用於發光二極體（LED）的色度分類。

關鍵字：照度計，色度計，資料比對

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I. INTRODUCTION

Color is an indispensable part of life for human beings. In the recent years, the rapid improvement of solid state lighting and the development of color identification sensors have been reaching to the blooms of applications [1-3]. The techniques and products of flat panel display are the mainstream of TV and monitor market today, and the manufacturers are striving for high added value and lowering the cost measurement solutions to enhance its competitiveness. The portable multi-color sensor measurement system is an excellent tool to achieve this purpose. It uses the primary-colors analysis methods and optical measurements software to measure chromaticity and luminance by the micro-processor, and then the measured data is directly put into ISD2590 voice single chip. The main features of the measurement system are: (1) Non-contact luminance and chromaticity measurement for color recognition. (2) Memory for storing 7 recognizable channels of reference color data. (3) User friendly interface that switches the mode selected by a single button. (4) Noise immunity: Radio frequency Interference (RFI) and light source.

II. PRINCIPLE

Color can be regarded as an intrinsic physical property of an object or as a visual sensation. As a sensation, it results from three different types of the receptor cells in the retina which responds a different portion of the visual spectrum respectively. For the physical property, color is determined by the wavelength distribution of the transmitted or reflected light. Given the three primary colors which are red, green and blue, it is possible to mix them in proportions that will match any sample [4-7]. Thus, a color transmission of sample can be specified in terms of X_R, Y_G, and Z_B, which are the amounts of the three primary colors required to match the sample. The ratio of the output voltage is expressed in percent as follows

$$X_R=R/(R+G+B)$$
$$Y_G=G/(R+G+B)$$
$$Z_B=B/(R+G+B) \quad (1)$$

where R, G, and B is the red, green, and blue light output voltage in RGB color photodiode sensor. Photodiode is operated by absorbing of photons and generating a current of flow in an external circuit proportional to the incident power. Exposing the P-N junction photodiode to the optical radiation, it produces the photocurrent I_p given by

$$I_p = \eta \times q \times E_e \times A_d \times (\lambda/hc) \quad (2)$$

where η is the quantum efficiency (the number of photoelectrons generated per incident photon in the photovoltaic case), E_e is the incident radiant flux density (irradiance) in Wcm^{-2}, A_d is the area of photovoltaic device, c is the speed of light, and h is Planck constant by $h=6.6\times10^{-34}$ W × sec^2. Fig.1 shows the scheme of measure system. We can see the circuit connection with operational amplifier and photodiode [8].

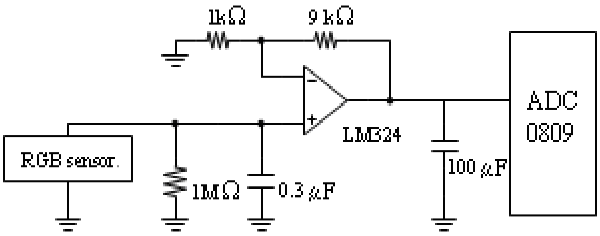

Fig.1. photodiode operation circuit.

The output voltage V_{out} from DC through the low-frequency region is in phase with the input current. The RGB sensor converts the light into electrical current. The photo current was transferred into the voltage with the parallel 1MΩ resistor at input terminal of amplifier. Add individually C_{in} (0.3 µF) and C_{out} (100 µF) parallel at input terminal and output terminal of the amplifier to filter high frequency noise of RGB sensor, and it reduce the environmental immunity. The effective voltage gain of the non-inverting amplifier is set by the resistance ratio R_f(9kΩ)/R_{in}(1kΩ) shown in Fig.1. An operation amplifier connected to the output of the analog Multiplexers/De-multiplexer (74HC157 IC in Fig.4) raises the small output signal to about tenfold and the contrast of this system.

III. THE MEASUREMENT SYSTEM

This paper, we introduce an innovation

measurement system by using the seven color balls which are red, orange, yellow, green, blue, indigo, and purple. These multi-color ball sensor detect the chromaticity of the tested sample quickly and easily compared to the ready use spectrophotometer. The reason to choose seven colors are that these colors are typical used in commercial color products. The measurement method is if the chromaticity data base of seven colors is constructed, then it will be used the reference standard applied to the production test of the unknown samples. The seven RGB color ball sensors shown in Fig. 2 and 3 detect the color sample and recognize the sample with data comparison technique. The emission spectrum of the under tested LED as the light source is matched with the peak absorption's wavelength of the RGB color sensor. The advantages by using the LED are the small size, short response time, long lifetime, and stable performance.

Fig.2. The color balls test device.

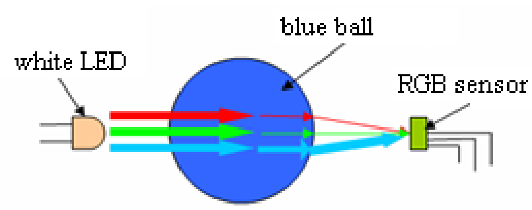

Fig.3. Ray trace of the tested color by color ball test device.

In traditional spectro-photometer, the color sensor is made by silicon photodiode which has one analog output channel. The three sub pixel sensor of the seven RGB color sensors has a total of 21 analog output channels in this system. Therefore, multiplexer circuit and software are challenged to design. To manage the massive amounts of analog signal, the analog Multiplexers/De-multiplexer is connected to the output of the RGB color sensor. An operation amplifier is served to the output of the analog Multiplexers/De-multiplexer to raise the small output signal to about tenfold, raising the contrast of this system. Before the signal enters microprocessor, the analog signals are converted into the digital signal by the A/D converter. The software in the microprocessor manipulates the digital signal, as well as compares the data for color recognition. We use the 1931CIE（International Commission on Illumination）tristimulus, X_R, Y_G, and Z_B, which are roughly red, green and blue, respectively, for color recognition to immunity the float of output voltage of RGB sensor. The data base of the microprocessor has X_R, Y_G, and Z_B of seven balls at the linear fluorescent conditions. When the microprocessor receives the interrupt command of the push bottom, the white LED emits visible light. The voice IC enabled by the subprogram, produces a series of sounds corresponding to the color sample.

The whole system is shown in Fig.4. According to the previous discussions, the system is composed of the followings: (1) the seven RGB sensors are group according to Reds, Greens and Blues.(2)TheAnalog Multiplexers/Demultiplexer and Operational amplifier (3) the A/D converters and 2-input multiplexer (4) 8051 single chip microcontroller, single chip voice record and playback device and seven push button pieces(S1....S7).

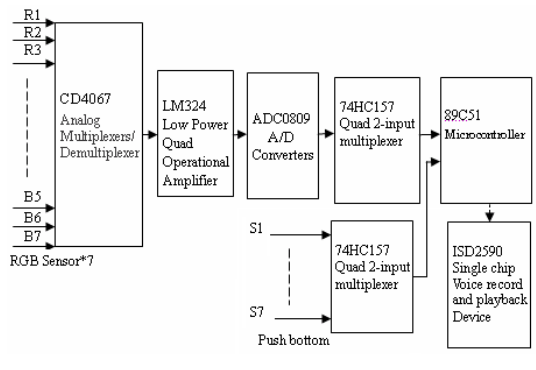

Fig.4. Seven color ball sensors measurement system.

The measurement procedures are shown as followings:

(1) Initiate 89C51 microprocessor and execute main program shown in Fig.5. Then,

Step.1: Check and see if button is push.
R3=0(register 3=0), the INTT0 subprogram interrupt button not push, Re-check register. (as shown in Fig.6 (a))

R3=1(register 3=1), the INTT0 interrupt button is push, Processor to next step (as shown in Fig.6 (b)).

Step.2: Read the digital signal from the Analog-to-Digital Converters into microprocessor memory.

Step.3: Calculate X_R, Y_G, and Z_B for each sensor and compare it with X_R, Y_G, and Z_B Data shown in Table 1.

Step.4: After calculation, the Processor sends signal to the 74HC157 (analog multiplexer IC) to switch the input signal form ADC0809 to the button.

(2) When INTT1 subprogram interrupt button is pushing (see Fig. 6(b)):

Step.1: Read the signal from the push button.

Step.2: Determine the specific button of the signal by matching the signal with the data in memory.

Step.3: Voice IC (ISD2590) produces the sounds that match the sensor reading for 3 second.

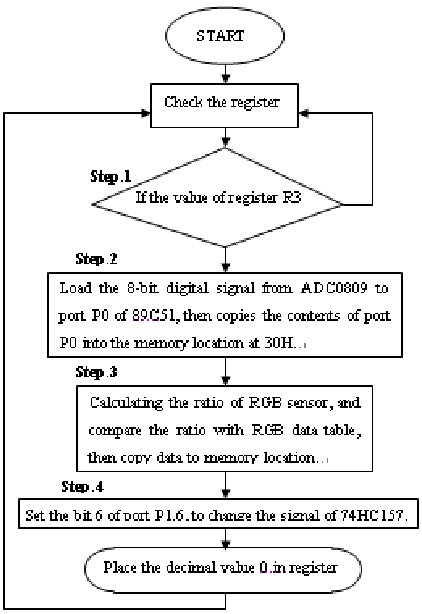

Fig.5. Main program flow chart.

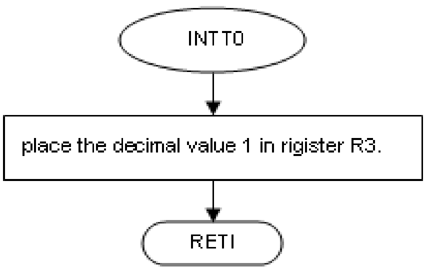

Fig.6. (a) Interrupts 0 subprogram flow chart.

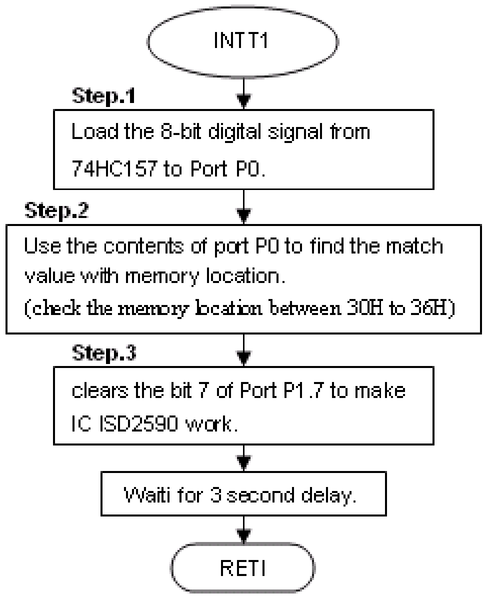

Fig.6. (b) Interrupts 1 subprogram flow chart.

Table 1. The XR:YG:ZB table of color balls

Color ball	X_R:Y_G:Z_B			
Red	4:3:3	3:2:4	2:3:4	3:3:4
Orange	5:2:2	4:2:3	4:3:3	4:2:3
Yellow	4:3:2	3:3:2	4:3:2	3:3:2
Green	3:3:3	4:3:4	4:4:3	4:4:4
Blue	2:2:4	2:3:5	2:3:4	2:2:4
Indigo	2:2:5	1:2:6	1:1:7	1:1:7
Purple	3:2:4	3:2:4	3:2:4	3:2:4

IV. EXPERIMENTS AND RESULTS

The conditions and specifications used for the experiment are listed in Table 2. The experiment uses seven RGB sensors, seven high power white LED, seven difference color plastic ball, a polishing steel ball, and a optoelectronic circuit board. The color of the plastic ball is uniform. The spectral response of RGB sensors is shown in Figure 7. The RGB Sensor and white LED is set in the two sides of the hole of color balls test device. The distance between them is about 40 mm.

Table 2. Conditions and specifications of the system

Operating wavelength	400nm~700nm
RGB Sensor	(a)3-channel (RGB) photodiode sensitive to the blue (λp=460 nm), green (λp=540 nm) and red (λp=620 nm) regions of the spectrum.(b) Active area: 3-segment (RGB) circular active area of φ2 mm.(c)spectral response as shown FIG.5.(d)Non-reflective black sleeve.
Plastic color ball	the X_R:Y_G:Z_B of seven balls is showed Fig 2
white LED	(a)Emitting Color ： White,(b) Luminous Intensity 1100 mcd @ Forward Current 20mA, Reverse Voltage 5volt.
Dynamic range	-0.3V~3.4V
Noise	Dark current～10nA
Environmental intensity of illumination	Fluorescent lamps: color temperature 4100K,750 lumens

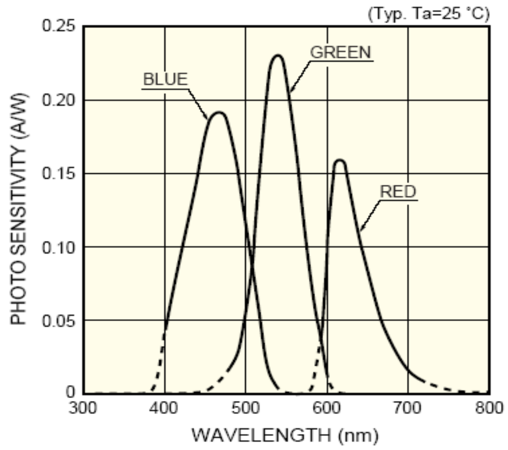

Fig.7. The spectral response of RGB Sensor.

Experiment procedures are as followings:

(1) Put color balls in the hole of color ball test device and 8051In-Circuit Emulator (ICE) tester set up.

(2) Built and record the look up table of X_R: Y_G: Z_B of color balls at the different environmental intensity of illumination.

(3)When the system power on, the detection of color balls are ready.

(4) When one color ball is press down, the push bottom switch is enabling and the color ball is detected.

(5)The loudspeaker will send out corresponding sounds of the color ball.

(6) repeat fifty times from (4) to (5).

According to the arrangement, there are seven kinds of color ball producing 5040 combinations in this system. We put reference color ball in responding hole of color balls test device, i.e., red color ball was set in the red hole, and vis-à-vis. Every color ball must be tested for 100 times and the detection error of the corresponding color ball is recorded. The detection error of the system is less than 0.1 % shown in Fig.8. The RGB sensor put on non-reflective black sleeve then gives this system immunity from environment source.

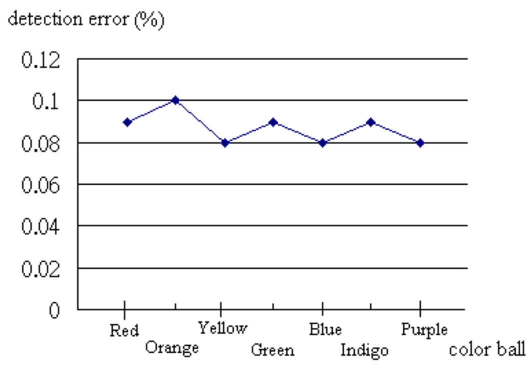

Fig.8. Detection error of the system vs. color ball.

V. CONCLUSIONS

By this research, we can see the multiplexer circuit, IC chip choice, seven RGB color sensors and the specified f X_R, Y_G, Z_B are used to implement the experiment. We offer a high speed and high sensitivity multi-color sensor measurement system for color recognition, audio signals output, automatic shade sorting and for automated batch process end-point controls. Our focus is to integrate E-O process applications for color control suit for the other applications (ex. food, drug, pigment and color material inspection …etc.).This system is programmable, and we use the same multiplexer algorithm to expand many RGB sensors at large measurement system. The characterizations of the seven ball sensors measurement system and Spectrophotometer are given in Table 3.

Table 3. Summary of the seven ball sensors

Item	Seven ball sensors measurement system	Spectrophotometer
Wavelength range	400nm~700nm	400nm~700nm
Detector	RGB sensor	Silicon photodiode array (dual 36-element)
Spectral separation device	No need	Diffraction grating
Probe number	Seven RGB sensors	One Silicon photodiode array
The measurement number per one time	Seven specimens (7 channels)	One specimen (1 channel)
Measurement time	10 msec	1 second
Dynamic range	0.2~3V	1V
Main function	Real time measurement and recognition	measurement
Light source	White LED	Pulsed xenon lamp (with UV cut filter)
Flexibility	Yes (special design)	No (general use)
Price	Cost effective	Expensive

Following the schedule shown in IV, it can be expected that an under tested color object will generate its corresponding color data table as Table 1. Once we get the reference color table of the under tested color object, then detection error is less than 0.1% and the whole procedure is easy, quick, and cost effective.

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REFERENCES

[1] Zheng, Y. L., Yang, S. H., Zhou, S. S., and Cao, C. J., “Research on uniformity of CIE 1976 LAB color difference formula,”Pachaging Engineering, Vol.26, No2, 2005.

[2] Guo, Y. and Fan, J. Y., “color difference of green jadeite jade in even color space,”ACTA Petrologica Et Mineralogica, Vol.23 No.1, pp. 65-68, Mar 2004.

[3] McDonald, R., “Acceptability and Perceptibility Decisions Using the CMC Colour Difference Formula ,”Textile Chemist and Colorists 20-6, pp. 31-37(1988) and Errata, Vol. 20, No. 8, p.10 (1988).

[4] Eberhardt, K., Neidlinger, T., and Schubert, M. B., “Three color sensor based amorphous n-i-p-i-n layer sequence,”IEEE Transactions on Electron Device, Vol. 42, No. 10, pp.1763-1768, 1995.

[5] Javier H. A., Raymond, L., Lee, J., and Javier, R., “Calculating Correlated Color Temperatures Across the Entire Gamut of Daylight and Skylight Chromaticities,”Applied Optics, Vol. 38, No. 27, pp. 5073-5079, Sep. 1999.

[6] Sharma, G. and Trussell, H. J. “Digital color imaging,”Image Processing, IEEE Transactions on, Vol. 6, No. 7 pp. 901 -932, July 1997.

[7] Masato, A., Hiroaki, I., Yasuhiko, H., and Matsuroh, N., “A Method to Estimate Correlated Color Temperatures of Illuminants Using a Color Video Camera,”IEEE Transactions on Instrumentation and Measurement, Vol. 40, No. 1, pp. 28-33, Feb. 1991.

[8] Graaf, G. R. and Wolffenbuttel, F., “Light-to frequency converter using integrating mode photodiodes,”IEEE Transactions on Instrumentation and Measurement, Vol. 46, No. 4, pp.933-936, 1997.