Colour recognition system based on TCS3200D

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Abstract

The colours of objects can be converted into pulses with different frequencies by TCS3200D. Colour recognition system was designed through the combination of Single Chip Microcomputer (SCM) and PC on the basis of the colour vision principle of TCS3200D. Fully utilizing TCS3200D, the system integrates the advantages of photodiodes and converter of light intensity to frequency to simplify circuit. The effects of factors, such as illuminant, orientation and the surfaces of objects, on the measurement were eliminated by the white balance adjustment. Additionally, colour vision errors were effectively reduced by the correction of the measured data with ANFIS and subtractive clustering.

Keywords: TCS3200D, colour recognition, ANFIS

1 Introduction

As an important application, colour recognition has been widely used in various industrial detections. A separate photodiode is covered with the corrected red, green and blue filters in the typical colour sensor at present. Then, colour signal is recognized by the corresponding processing of the output signal. Some sensors combine two steps together to output analog signal. However, front channel processing, such as amplification, filtering and A/D conversion, should be conducted before computer processing in order to perform recognition. Consequently, the complexity of the circuit increases with a large recognition error, affecting the results [1]. Colour recognition is realized by TCS3200D made by TAOS (Texas Advanced Optoelectronic Solutions) Company. Square wave with a 50% duty cycle is directly produced by the conversion of light intensity to frequency of TCS3200D. Meanwhile, the output using the digital interface brings many new, excellent properties to TCS3200D.

2 Colour recognition principle of TCS3200D

2.1 RGB MODEL

The surface of object absorbs part coloured components in white light (sunlight) shining on it and reflects the other coloured parts to the eyes. Any colour can be obtained by the mixture of three primaries (red, green and blue) in different ratios. Three axes represent R, G and B in the RGB model of colour space (Figure 1). Origin corresponds with black (0, 0, 0), and the vertex farthest away from the origin white (255, 255, 255). The line connecting the origin with the farthest vertices represents grayscale distribution from black to white. The other six vertices of the cube represent red, yellow, green, cyan, blue and magenta, respectively. Each colour has a corresponding RGB value [2].

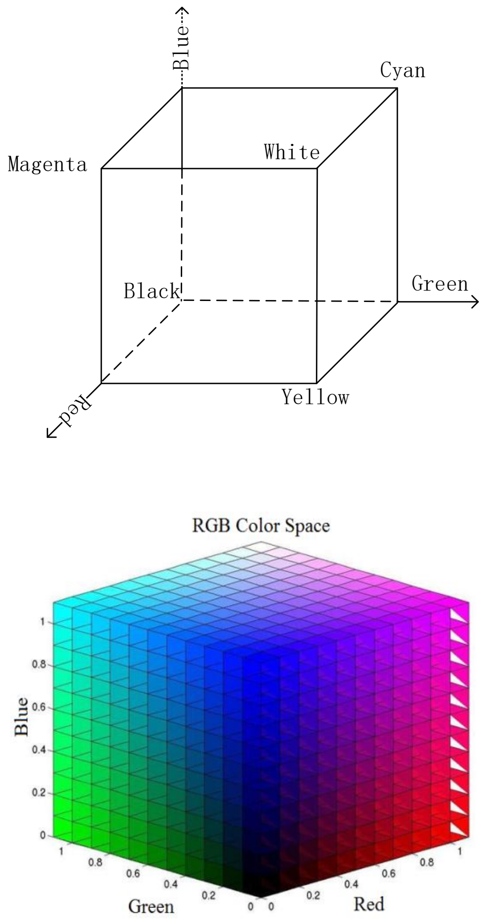

FIGURE 1 RGB model

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2.2 COLOUR RECOGNITION PROCESS OF TCS3200D

The colour of the tested object can be obtained with known RGB values according to the RGB model of colour space. TCS3002D only allows some particular colour to access but prevents the other colours after a colour filter is chosen. For example, only red incident light can access if red filter is chosen, while blue and green will be prevented. Then, the red light intensity can be measured. Similarly, the intensity of the blue or green light can be obtained if the other filters are chosen. RGB values are quantized by the linear conversion of light intensity to frequency signal. Then, the colour of the light projected to TCS3200D can be analysed.

The quantization process of RGB values is as follows. First, the RGB intensity value of reference light () was measured. Then, the intensity value $\left(P_{or}, P_{og}, P_{ob}\right)$ of light reflected by object was obtained under standard light. The ratio of two values was the reflection/transmission property of the object - the actual colour of the object (Equation 1).

$$K_r = P_{or} / P_{sr}, K_g = P_{og} / P_{sg}, K_b = P_{ob} / P_{sb} . \quad (1)$$

The standard coordinate of colour is among 0 to 255 in the RGB coordinate, so the standard RGB values were obtained by the result multiplied by 255.

2.3 WHITE BALANCE ADJUSTMENT

It should be noted that different light reflected by the object has different light intensities. Moreover, intensity components reflected by the object are different for non-standard white light (three unequal RGB values). Theoretically, white is composed by the same amount of red, green and blue. However, the amount of three primaries actually is not entirely equivalent in white. Equation (1) can be used to eliminate the effect [3]. The ratios are all 1 when an object is white. Therefore, the ratios multiplied by 255 were (255, 255, 255) —RGB values.

On the other hand, TCS3200D has different sensitivities to three primary colours, resulting in three unequal RGB values. The light intensity values $\left(P_{or}, P_{og}, P_{ob}\right)$ of three primary colours are not equal with the same induction time when TCS3200D is under white light. Therefore, white balance adjustment should be carried out before the test, adjusting the TCS3200D induction time of three primaries. For instance, induction time should be decreased with a higher sensitivity of red; otherwise the time should be increased. The induction time of three primary colours is determined as follows. First, the filters of three colours are sequentially gated, and then the output pulses of TCS3200D are counted. The time of pulses getting through each channel is calculated when the count is 255. The time is corresponding to the time standard used by each TCS3200D filter in actual tests. The numbers of pulses measured during the time are corresponding light intensity values - P_{or}, P_{og}, P_{ob} values.

3 TCS3200D

TCS3200D is the programmable converter proposed by TAOS Company of colourama to frequency. It integrates configurable silicon photodiode and a current-to-frequency converter on a single CMOS circuit. Moreover, three filters (red, green and blue (RGB)) are integrated on a single chip. Different combinations of pins S2 and S3 are controlled by photodiode, thus selecting different types of filters. Square waves with different frequencies (50% duty cycle) are outputted after current-to-frequency conversion with incident light projecting onto TCS3200D, corresponding to different colours and light intensities. TCS3200D can be directly connected to microprocessors or other logic circuits because the output signal with digital quantity can drives standard TTL or CMOS logic input. In addition, A/D conversion circuit is no longer needed because digital output can realize the conversion precision of more than 10 bit in each colour channel. Thus, the circuit becomes simpler. The pin and the function of TCS3200D are shown in Figure 2 [4].

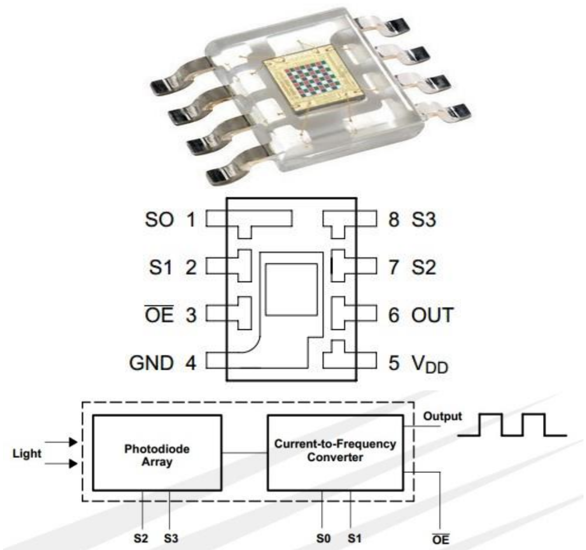

FIGURE 2 Pin and function of TCS3200D

TCS3200D (Figure 2) uses the 8-pin SOIC surface-mount package and integrates 64 photodiodes on a single chip. The photodiodes are classified into four types—16 with red filters, 16 with green filters, 16 with blue filters and the rest without filters (all optical information can access). The unevenness of the incident radiation is maximized through the stagger of these photodiodes in the chip, thus increasing the accuracy of colour recognition.

On the other side, the 16 multiple-connected photodiodes with the same colour are distributed evenly throughout the array to eliminate location bias among colours. The typical range of output frequency is 2~500KHz. Users can choose the output scale factor (100%, 20% or 2%) or power down model *via* two programmable pins. The sensor output is applicable to different measurement ranges through the scale factor, improving its adaptability. For example, a small scaling value is selected to make the output frequency of TCS3200D match counter when low-frequency counter is used. The available combinations of S0, S1, S2 and S3 are shown in Table 1.

TABLE 1 Options of combinations

S0	S1	Output frequency scaling	S2	S3	Filter type
L	L	Power down	L	L	Red
L	H	2%	L	H	Blue
H	L	20%	H	L	Clear
H	H	100%	H	H	Green

4 Practical applications of TCS3200D

The hardware structure in this system adopted SCM application system and modular design. The principle block consists of LED module, colour recognition module, a microcontroller module and host computer module, as shown in Figure 3. Furthermore, display module, data storage module, operation module and serial communication module were included in the host computer module. The LED module improves the accuracy of colour recognition. The uniform arrangement along circle of four high-brightness, white LED makes the cross-section intensity of emitted beam evenly distributed, thus obtaining better recognition effect.

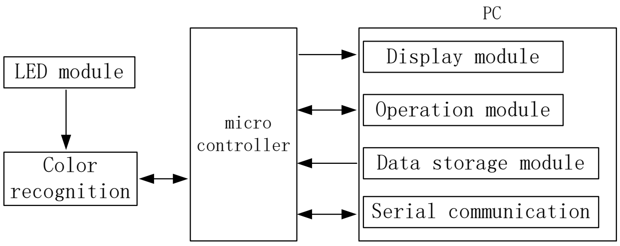

FIGURE 3 Connection between TCS3200D and Microcontroller

Microcontroller was connected to TCS3200D through SCM STC89C51 (Figure 4). First, TCS3200D driver determined whether white balance was need, and then the TCS3200D filters were gated successively. Subsequently, the timing was performed on the basis of the time standard in white balance adjustment. Meanwhile, the number of TCS3200D output pulses was counted. Finally, the results were transmitted to the PC through the serial port.

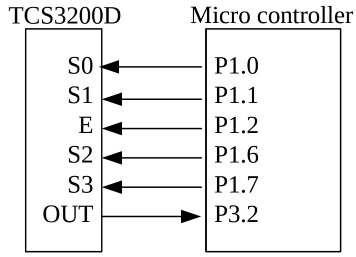

FIGURE 4 Connection between TCS3200D and Microcontroller

5 Colour vision optimization with ANFIS and subtractive clustering

The colour sensor and hardware circuit design can cause some systematic deviations of system measurement, which cannot be described with existing physical knowledge. There is an unknown nonlinear relationship between the output value and the actual value of sensor. With strong nonlinear approximation ability, ANFIS (Adaptive-Network-based Fuzzy Inference System) is entirely feasible to the non-linear calibration of sensor. Therefore, the calibration model based on ANFIS and subtractive clustering was adopted for the correction of the values measured by colour sensor.

First, samples were obtained by calibration experiment. Then, ANFIS network structure was determined by subtractive clustering. Subsequently, the system was trained with hybrid learning algorithm. Finally, the trained system was applied to the characteristic correction of sensor. The correction process is shown in Figure 5 and Figure 6 [5].

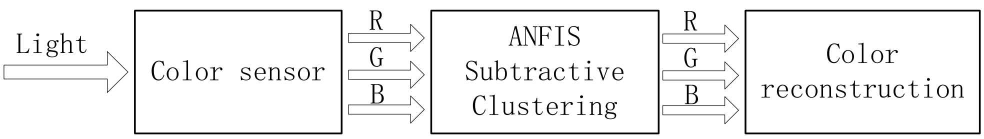

FIGURE 5 Optimization of colour sensor's output

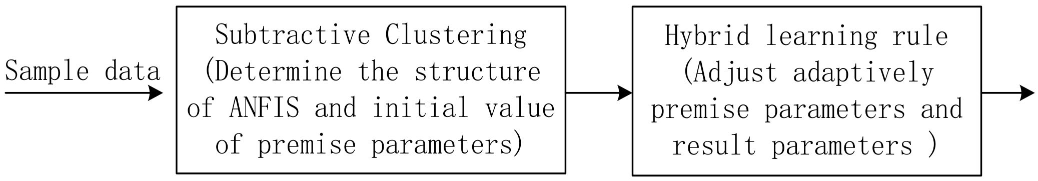

FIGURE 6 Process of designing ANFIS

Each output corresponds to a three-input and single-output ANFIS system (Figure 5). It should be noted that calibration points cannot be arbitrarily selected for training samples, while sample data should be selected on the basis of certain law. Thus, the data are representative so that correction model ANFIS is finally obtained with higher accuracy and universal applicability. The more the selected samples are, the better the correction effect of the model on results will be. Varying among 0-255, RGB selected the values of five specific points—0, 64, 128, 192 and 255. There are a total of 125 sample data, used to build correction model ANFIS [6].

ANFIS was used to compensate the sensor output as follows:

1) The related training and test samples were obtained.

2) The fuzzy rules of ANFIS and the initial values of parameters were determined using subtractive clustering according to training samples.

3) ANFIS training was conducted, and its performance was judged using test samples. If the performance was not good, then the evaluation threshold of clustering centre should be modified in the clustering algorithm. Thus, the number of ANFIS fuzzy rules was changed until ideal correction results were obtained.

4) The sensor output of actual colour was corrected using ANFIS trained well.

The data sent by the SCM through serial were processed using VISUAL C++ programming at the PC-terminal. The colour vision results, optimized using ANFIS and subtractive clustering, are shown in Figure 7. As can be seen from Figure 7, the RGB values after recognition are very close to those of recognized colour. Therefore, the effect of colour vision is excellent.

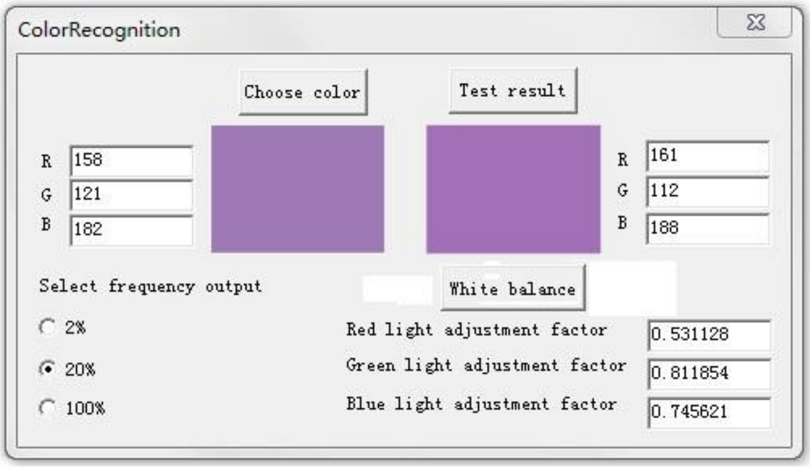

FIGURE 7 TCS3200D colour vision results

In addition, the following questions should be noted in the TCS3200D application:

1) Colour recognition is susceptible to interference from the external environment, e.g., stray light, etc., will affect the accuracy of colour recognition. Therefore, LED lighting system, the object to be tested and colour sensor were placed in the shading light cylinder in the design of system structure. Then, the effect of light from the outside world can be avoided during colour measurement to reduce measurement errors.

2) White balance adjustment is necessary for the first use of TCS3200D, reboot, replacement of lighting source, etc.

6 Conclusions

Light, observation orientation and surface of measured object and other factors have important effects on measurement results, which is the difficulty in colour measurement. The colour vision principle of TCS3200D was analysed, and its characteristics, such as high integration and digital output interface, were fully used. The output data of sensor was collected through SCM STC89C51, avoiding complex circuit processing. LED light effectively eliminates the effect of light instability on measurement. Client was designed through VC++ at the PC-terminal. Moreover, ANFIS and subtractive clustering were used to optimize the results of colour vision, thus greatly reducing measurement error. TCS3200D can be widely used in various industries where the measurement, analysis and recognition of light colour components are required.

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