Color Recognition Using High Speed Single Chip Color Processor

Ansgar Wego, Frank Stuepmann
Silicann Technologies GmbH, Rostock

Abstract

The chip-design described in this paper is a high speed single chip color processor which includes all required circuitry to directly tie RGB color sensor current signals to the chip. To improve the sensor signal robustness, an ambient light suppression has been implemented.
The chip is capable of storing up to 16 color patterns via teaching-in in. To achieve a perceptive color preprocessing, the RGB sensor signals (correlating with CIE1931 color-matching functions) are mapped onto CIELab color space coordinates. This transformation advantageously delivers perceptive color recognition results which comply to the pretensions of a human observer. The color signal processing path of the chip is almost analog, while the control, storing und communication units are generally digital.

Introduction

For high speed manufacturing of colored products, a rapid color checking system is essential to ensure the quality of the color attributes of these products. Furthermore, for high speed color sorting of objects such rapid systems are needed too.
To achieve high speed color checking, an almost analog integrated circuit has been designed. This circuitry is intended to process all signals in parallel. A unique feature of the integrated processor is to treat the color signal evaluation perceptive. That means, color differences of objects are evaluated human like. The perceptive color treatment is possible due to a special color preprocessing circuit.
The starting point for the perceptive color processing constitutes a special color sensor that implements the CIE1931 color-matching functions (also known as CIEXYZ) for the standard observer [1]. This so called true color sensor is made of 3 silicon PIN photo diodes integrated on a single chip. Each of the photo diodes is sensitized with a dielectric spectral filter. Fig. 1 shows typical normalized filter curves of the sensor [2].

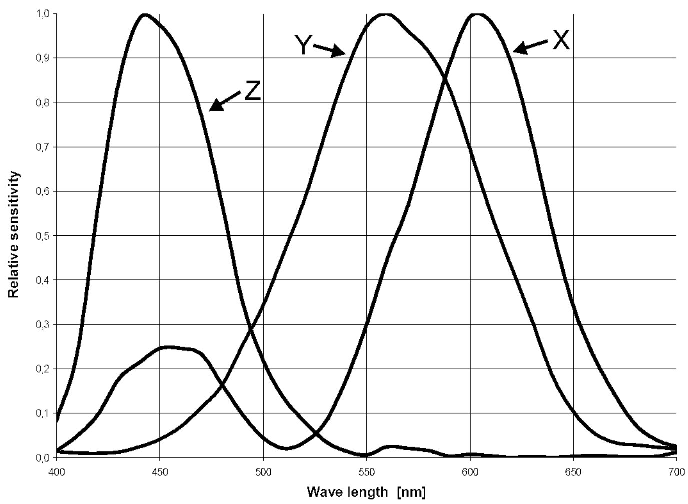

Fig. 1: Normalized filter curves of the true color sensor [2]

Signal preprocessing

The photodiodes of the color sensor deliver current signals that depend on the light intensity to which the diodes are exposed. To interface different amperages of the sensor, a programmable transimpedance amplifier was designed.

The sensor receives light signals that are normally interfered by ambient light sources. If the intensities of ambient light sources are significant, the results of the color recognition process is unusable. Therefore a high dynamic ambient light suppression circuit was designed. The concept is illustrated in Fig. 2. A switch is toggled synchronously to a switched measuring illumination. The circuit only amplifies the difference between the light phase and the dark phase of the measuring illumination. Frequencies up to the megahertz region are possible.

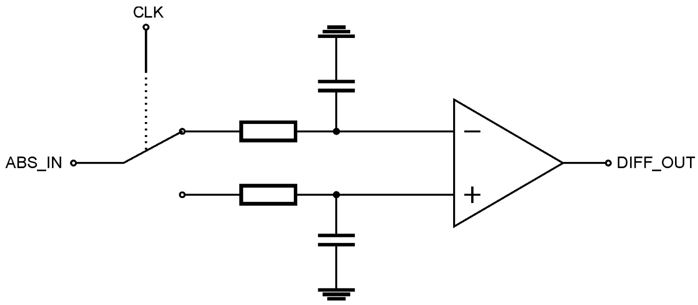

Fig. 2: Ambient light suppression circuit concept

For the perceptive color processing, the signals are emphasized by nonlinear operations according to the CIE1976 [3] transformation recipe (Equ. 1-3)

$$L^* = 116 \cdot \sqrt[3]{Y/Y_R} - 16 \tag{1}$$

$$a^* = 500 \cdot \left[\sqrt[3]{X/X_R} - \sqrt[3]{Y/Y_R} \right] \tag{2}$$

$$b^* = 200 \cdot \left[\sqrt[3]{Y/Y_R} - \sqrt[3]{Z/Z_R} \right] \tag{3}$$

The equations are not valid for values of X/X_R, Y/Y_R and Z/Z_R less than 0.008856, i.e. for very dark signals this transformation is not admissible.

The implementation of the transformation recipe was designed by analog circuitry. In the equations the cubic root has to be solved. This can be don by log/antilog conversions. As a consequence, the exponential operations are reduced to multiplication (division) operations. The log/antilog functions are designed by operational amplifiers with nonlinear feedback devices (diodes). The circuit is designed to fulfill the speed requirements of the color sensor.

Color processing

Fig. 3 shows a block diagram of the IC concept. The true color sensor approximately delivers XYZ signals according to the CIE1931 color-matching functions. The sensor can bee directly connected to the XYZ inputs of the chip. After ambient light suppression, the signals are perceptively emphasized as described above. The $X_R Y_R Z_R$ signals are required to determine the reference white values necessary for the transformation recipe (cf. equ. 1-3).

After the preprocessing steps, the signals are fed through a parallel distributed analog circuitry. This network like circuitry is designed to calculate the minimum squared distances of a given color input vector to all 16 color vectors stored in color patterns table in parallel (4).

$$MD_N^2 = \sum_i \left(I_i - CP_{i,N} \right)^2 \tag{4}$$

MD_N^2 denotes the minimum values of the calculated squared distances. I_i is an input vector component and $CP_{i,N}$ a component of the N[th] stored color table pattern. The distance signals MD^2 are used for subsequent evaluation processes.

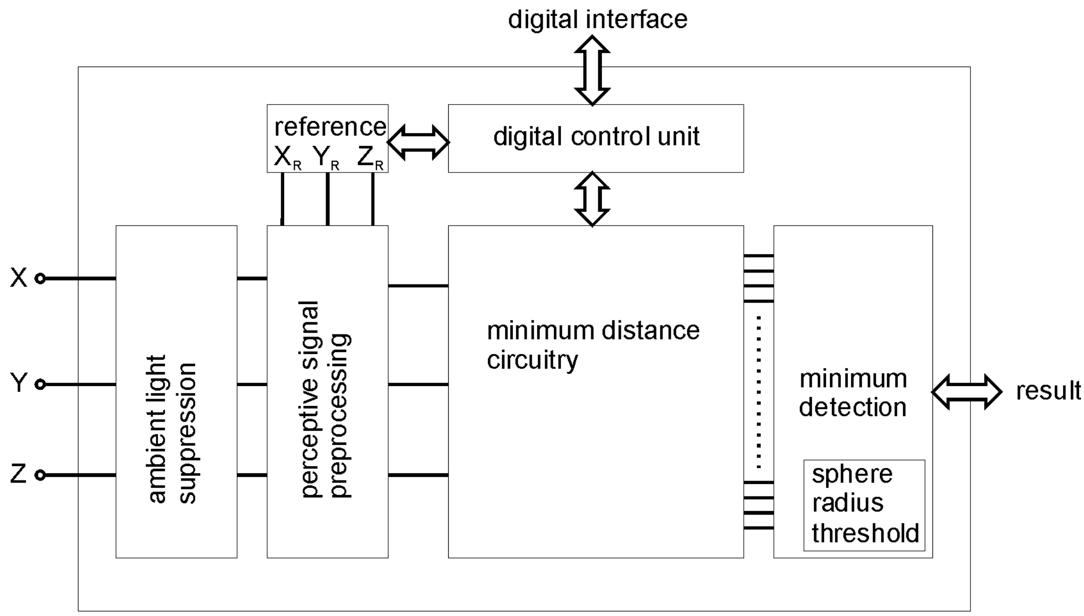

Fig. 3: Block diagram of the color processor

Two evaluation modes are planned. In the first mode colored objects are assigned to an appropriate color pattern of the color table. The mode is called classification mode. To detect the appropriate color class the smallest distance value must be determined. For that, a minimum detection circuit was implemented. The minimum detection unit requires a start impulse to initiate the detection process. The circuit is designed in a hierarchical way (cf. Fig. 4). The result of the minimum detection is the smallest distance value and a binary value that codes the appropriate color class index.

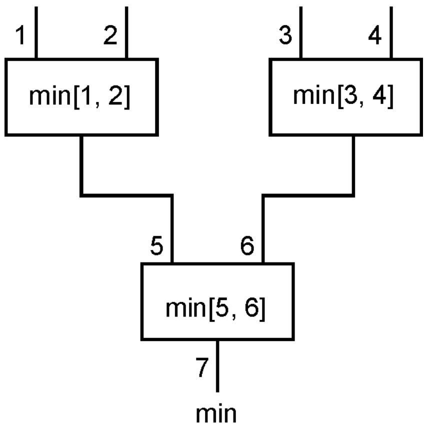

Fig. 4: Hierarchical structure of the minimum detection unit

The second mode is called recognition mode. In this mode, thresholds are defined to characterize valid boundaries of regions that belong to the same color class. A consequence of the perceptive color signal preprocessing is that class boundaries can generally be approached with simple spheres. Therefore, in color recognition mode, only a maximum radius as a threshold for the class boundary sphere must be defined. The distance signal MD^2 between the color input vector and the assigned appropriate color class must be located within this sphere to be accepted as “recognized”. Fig. 5 shows a diagram that illustrates the processing in principle. For simplification, the figure shows a two dimensional input space with three stored color patterns ($\underline{CP}_1, \underline{CP}_2, \underline{CP}_3$) which define three classes. The radius R is the valid threshold for a class recognition. In the example of Fig. 5, two input signals ($\underline{I}_1$ and $\underline{I}_2$) are located within the circle of radius R. The third color input vector ($\underline{I}_3$) lies outside the boundary of the closest color pattern region ($\underline{CP}_3$) and will therefore be rejected as “not recognized”.

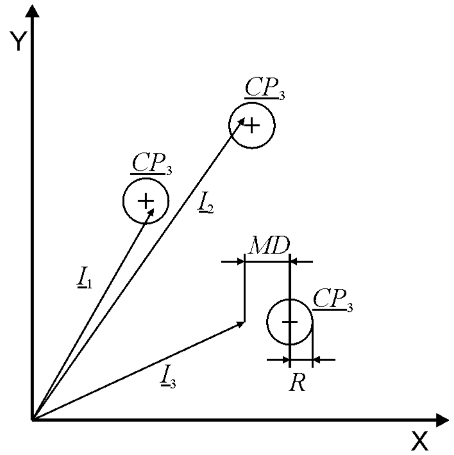

Fig. 5: Distance diagram for three color patterns and color input vectors

Summary

The presented design for a single color processing chip is suitable for a high speed checking or sorting system. The analog signal path and the parallel distributed circuit implementation method enables a very high processing performance. Furthermore, the design is cost efficient and allows low power applications.

References

[1] ISO/CIE 10527: Colorimetric observers, 1991

[2] Data Sheet: MTCS3 series 3-range color sensors, Laser Components GmbH, Werner-von-Siemens-Str. 15, D-82140 Olching, 2004

[3] CIE DS 014-4.1/E:200X, Colorimetry – Part 4: CIE 1976 L*a*b* color space, Draft 04, 2003

Contact address

Dr.-Ing. Ansgar Wego, wego@silicann.com
Dr.-Ing. Frank Stuepmann, stuepmann@silicann.com
Post address:
Silicann Technologies GmbH
Joachim-Jungius-Straße 9
D – 18059 Rostock