# New High-resolution Technique of Image Reading Using LMS-Type Spectrum Filter

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## Abstract

*This paper proposes a new technique of image reading for printed material using a one-chip image sensor that enables high resolution and solves the problem of false colors around pattern edges. To achieve this, the technique adopts a novel method that produces a color component value of a pixel that is not sampled based on the supposition that there is only one color dot in the background color of printed matter in small areas such as the aperture areas of the pixels of the image sensor. Based on this supposition, we derive the linear relationship between the color component and luminance in such small areas. In addition to using this linear relationship, using a color filter with a wide band transmission spectrum also contributes to achieving high resolution with this technique. We conducted a simulation where we used an LMS-type color filter as a wideband spectrum filter. The results from the simulation demonstrated the effectiveness of this method indicating that we could obtain high resolution for all color component signals as high that of a 3-chip color image sensor and it could improve color reproductivity around pattern edges.*

## Introduction

Image sensors have thus far greatly evolved in terms of resolution sensitivity and reduced size. Size reductions have enabled image-input devices such as digital cameras and image scanners to become very compact and this has spread their applications. Methods that use one-chip sensors have an advantage to those that use three-chip sensors for reading color images from the point of view of compactness. However, one-chip sensors have some shortcomings. The biggest is that they have lower resolution than three chip sensors. In addition to lower resolution, they have problems with false colors around pattern edges. This results from differences in the sampled pixels in color components because only one color component can be sampled at each pixel. Various techniques of interpolation have been studied to produce color component signals at pixels where they are not sampled [1]–[3]; however, the problems with false colors around pattern edges have not been resolved. Moreover, the resolution of color component has not been improved by these techniques because interpolation increases the appearance of the number of pixels but not actual ones in which color components are sampled.

This paper proposes a new technique that enables high resolution and solves the problems with false colors around pattern edges in reading images for printed material. To achieve this, the technique adopts a novel method that produces color components based on the supposition that for small areas, color components and luminance have a linear relationship. Moreover, this technique uses a color filter with a wideband transmission spectrum to achieve high resolution and accurate color reproductivity around pattern edges. We conducted a simulation, which demonstrated the effectiveness of this method, where we used a LMS type color filter as a wideband spectrum filter. This paper also describes the simulation and the results we obtained from it.

## Proposal

The technique we propose assumes that there are only two colors in small areas of printed color images such as the aperture of the pixel of the image sensor, i.e., a colored dot and a background, as shown Fig. 1. If we use an LMS color component in these cases, the signal from the pixels for each color component is expressed by Eqs.1 – 3.

$$L = L_m P + L_u (1-P), , \qquad (1)$$
$$M = M_m P + M_u (1-P), \text{ and } \qquad (2)$$
$$S = S_m P + S_u (1-P), \qquad (3)$$

where P is the ratio of the color dot area in the aperture in Fig. 1, and $L_m$, $M_m$, and $S_m$ are the L, M, and S components for the color dot, and $L_u$, $M_u$, and $S_u$ are the L, M, and S components for the background. Luminance K is expressed as the linear summation in Eq. 4.

$$K = a_L L + a_M M + a_S S \ , \qquad (4)$$

where $a_L$, $a_M$, and $a_S$ are constants. Substituting L, M, and S in Eqs. 1–3 for those in Eq. 4, we can obtain Eq. 5.

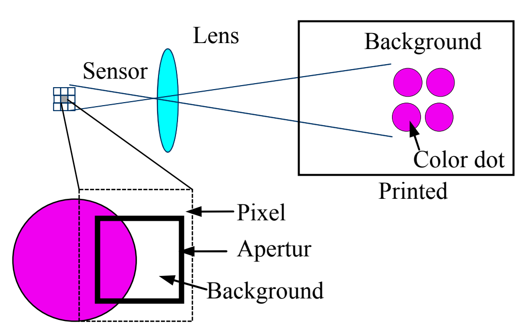


***Figure 1*** *Model of image reading for printed material.*



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$$K = C_p P + C_o \,, \qquad (5)$$

where $C_p$ and $C_0$ are constants and expressed by Eqs. 6 and 7.

$$C_p = a_L L_u + a_M M_u + a_S S_u \text{ and} \qquad (6)$$

$$C_o = a_L (L_m - L_u) + a_M (M_m - M_u) + a_S (S_m - S_u) \qquad (7)$$

We can obtain Eqs. 8–10 by substituting P in Eq. 5 for it in Eqs. 1–3.

$$L = C_L K + L_0 \,, \qquad (8)$$

$$M = C_M K + M_0 \text{, and} \qquad (9)$$

$$S = C_S K + S_0 \,, \qquad (10)$$

where $C_L$, $C_M$, $C_S$, $L_0$, $M_0$, and $S_0$ are constants. Eqs. 8–10 indicate that each color component L, M, and S, are linear to luminance K within a small area where there are only two kinds of colors, i.e., a color dot and a background, as shown in Fig 1. As the aperture of the image sensor is sufficiently small, there is only one color dot and a background in the aperture in almost all cases. Therefore, we can assume that L, M, and S are linear to luminance K within a small area based on Eqs. 8–10.

Figure 2 illustrates the process we used to obtain high-resolution color components L, M, and S and luminance K. Figure 2 (a) outlines the sensor layout. In Fig. 2 (a), G1 G2 and G3 indicate the pixel group which consists of three pixels for each color component.

The high-resolution process consists of four steps.

*Step 1:* First, we set the values of the L, M, and S component signals of the pixels, i.e., those that have not been sampled, to the same value as those of sampled pixels in the same pixel group shown in Fig. 2 (b).

*Step 2*: The value of the luminance K signal is determined by Eq. 4 for all pixels in the same group shown in Fig. 2 (c).

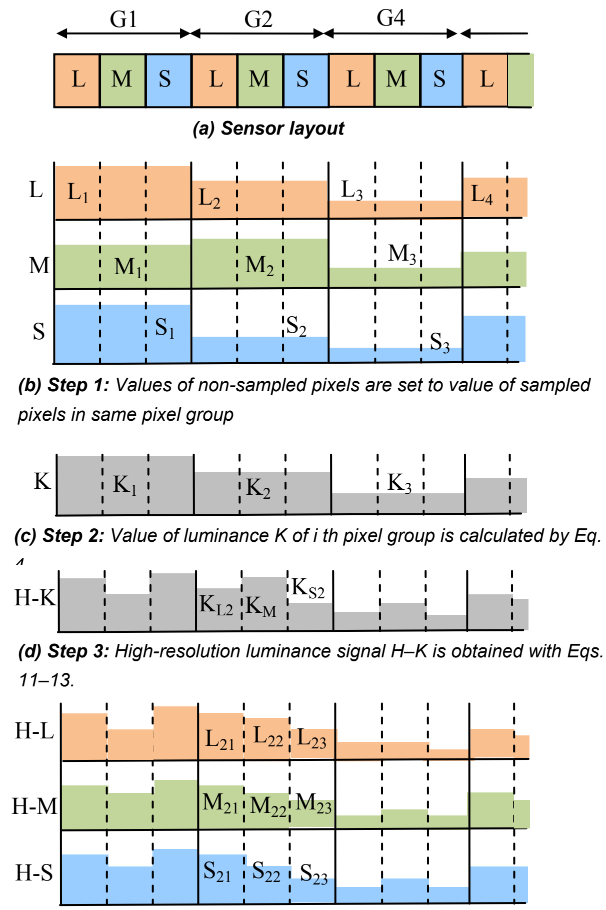
*Step 3:* Assuming that K and L (M and S) are linear as given in Eqs. 8–10, we obtain an approximate linear equation for K and L (M and S) from the data of L, M, S, and K of several neighboring pixel groups including noticing pixel group using the least-squares method, as given in Eq. 11–13.

$$K_L = r_L \frac{\delta L}{\delta K}(L - L_{av}) + K_{av} \,, \qquad (11)$$

$$K_M = r_M \frac{\delta M}{\delta K}(M - M_{av}) + K_{av} \text{, and} \qquad (12)$$

$$K_S = r_S \frac{\delta S}{\delta K}(S - S_{av}) + K_{av} \,, \qquad (13)$$

where $r_L$, $r_M$, and $r_S$ are the correlation coefficients of K and each color component, $\delta L$, $\delta M$, $\delta S$, and $\delta K$ are standard deviations of data used on L, M, S and K, and $K_{av}$, $L_{av}$, $M_{av}$ and $K_{av}$ are their averaged values. Using an approximate linear equation for K and L (M and S) given in Eqs. 11–13,




***(a) Sensor layout***

***(b) Step 1:*** *Values of non-sampled pixels are set to value of sampled pixels in same pixel group*

***(c) Step 2:*** *Value of luminance K of i th pixel group is calculated by Eq. 4*

***(d) Step 3:*** *High-resolution luminance signal H–K is obtained with Eqs. 11–13.*

***(e) Step 4:*** *High-resolution L, M, and S component signals H–L, H–M, and H–S are obtained with Eqs. 14–16*

***Figure 2*** *Steps for producing high resolution signal.*

we obtain high-resolution luminance signal $K_{Li}$ shown in Fig. 2 (d). The subscript L (M and S) of K indicates that this luminance signal is for a pixel where the L component signal is sampled and it is obtained from the data of L (M and S) and K obtained in Step 1. The subscript i of K indicates that it is the signal in the i-th pixel group.

*Step 4:* This is the step to obtain the high-resolution L, M, and S component signals shown in Fig. 2 (e). From Eqs. 11–13, we obtain Eqs. 14–16.

$$L' = r_L \frac{\delta L}{\delta K}(K - K_{av}) + L_{av} \,, \qquad (14)$$

$$M' = r_M \frac{\delta M}{\delta K}(K - K_{av}) + M_{av} \text{, and} \qquad (15)$$

$$S' = r_S \frac{\delta S}{\delta K}(K - K_{av}) + S_{av} \,, \qquad (16)$$

but we obtain the new Eqs. 14–16 above using several neighboring pixel group data of the high-resolution luminance signals obtained in Step 3 and the L (M and S) signal obtained in Step 1 in Fig. 2 (b) with a method similar to that in Step 2.

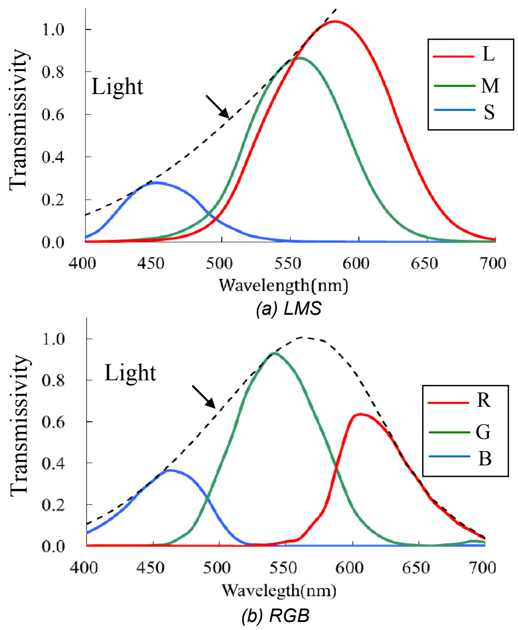



***Figure 3*** *Spectra of LMS and RGB color filters used in simulation.*

This technique can produce a color component signal with resolution as high as that of a three-chip image sensor. This is theoretically effective for an RGB color filter; however, if we use a wide band spectrum filter whose bands overlap like those in an LMS color filter, we can reduce the error in the luminance signal estimated in Step 3 and, as a result, we can obtain an accurate high-resolution color-component signal.

## Simulation

### *Method*

We simulated the technique we propose to confirm its effectiveness. Figure 3 shows the spectra for the LMS and RGB color filters we used in the simulation. The signals from each pixel were calculated with Eq. 17.

$$S_{i,j} = \int F_i(\lambda) P_j(\lambda) d\lambda\,, \qquad (17)$$

where Fi(λ) is the transmission spectrum of the i (i=L, M, and S) color filter and Pj(λ) is the reflection spectrum of the j (j=C, Y, and M) colored ink. We assumed the ink that was used was based on the "Japan Color" standard.

We studied what effect the use of LMS color filters those had wide band transmission spectrum compared to RGB color filters would have in this simulation. Moreover, we confirmed whether high-resolution reading was possible by checking the pattern edge of the line and space patterns.

We carried out the simulation on a linear sensor whose pixel layout is shown in Fig. 2 (a), and the data from 25 neighboring pixel groups were used to obtain an approximate linear equation for K and the color components in Eqs. 11–16.

### *Results and discussion*

Figure 4 presents the simulation results on what effect the different colored filters had. We can see that for the RGB color filter, the color component signal processed for high resolution is on an uneven level and the luminance signal was not sufficiently corrected. However, the color component signal for the LMS color filter processed for high resolution has fewer uneven levels and the luminance signal is sufficiently corrected. This is because signals that are close to the luminance signal can be obtained using the LMS color filter since their transmission spectrum is wider than that of the RGB colored filter.

Figure 5 shows the results for the simulation on the signal around the pattern edge of the line and space (white). Figure 5 (a) shows the original LMS component signal. We assumed the sensor had a pixel density of 600 DPI. Therefore, all LMS component signals were sampled at 200 DPI. Figure 5 (b) shows the signals produced by interpolation. We can see that the colors differ more than the originals around the edge; moreover, the curve is not sharp. Figure 5 (c) shows corrected luminance signals H-K. We can see from Fig. 5 (c) that H-K is even due to correction. Figure 5 (d) shows the LMS color component signal produced using H-K. It can be seen that the curve around the edge is sharp and colors are accurately reproduced.

The simulation results in Fig. 5 demonstrate that the proposed technique effectively improves the resolution of the one-chip image sensor.

## Conclusions

We proposed a new technique for improving the resolution of a one-chip color image sensor using an LMS type color filter. Based on the supposition that LMS color components are linear to luminance K within a small area, we could obtain high resolution LMS color component signals that were as high as those in three-chip color image sensors. We demonstrated the effectiveness of the technique we propose in a simulation.

## References

[1] H. Sugihara et al, "False Color Signal Reduction Method for Single-chip Color Video Camera", *IEEE Trans. Consum. Electron*. 40(2), pg.100. (1994).

[2] T. Kuno et al, "New Interpolation Method Using Discriminated Color Correlation for Digital Still Camera. *IEEE Trans. Consum. Electron*. 45(1), pg:259. (1999.).

[3] J.F.Hamilton Jr. et al, "Adaptive Color Plane Interpolation in single Sensor Color Electronics Camera", *US Patent* 5,629,734. (1997). (1998).

## Author Biography

*Hidekazu Sekizawa received his M.S. in Engineering from Niigata University, Japan. Since 1972, he has worked at the Toshiba R&D Center,*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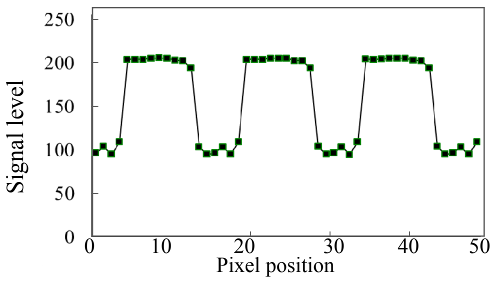
*Japan. He was involved in the first commercialization of desktop digital color copiers in the world in 1985. He retired from Toshiba in 2008. He joined Kanagawa Institute of Technology in 2009. His main aim is to take images even in the dark like paintings, which has been his life's work.*

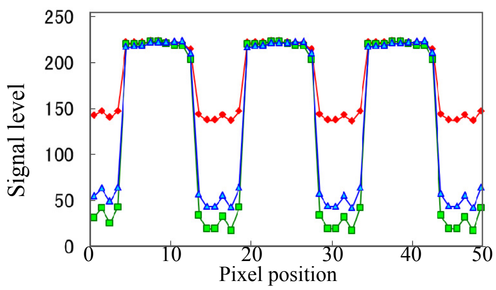
*Masahiro Suzuki received his B.A., M.A., and Ph.D. degrees in psychology from Chukyo University, Nagoya, Aichi, Japan, in 1994, 1996, and 2002, respectively. He joined Human Media Research Center, Kanagawa Institute of Technology, Atsugi, Kanagawa, Japan, in 2006. He is currently engaging in the research of Information Technology. Dr. Suzuki is a member of Society for Information Display, Vision Sciences Society, Vision Society of Japan, Optical Society of Japan, Japan Society of Kansei Engineering.*

*Kazuhisa Yanaka received his B.E., M.E., and D.E. from the University of Tokyo in 1977, 1979, and 1982. He joined the Electrical Communication Laboratories of NTT in 1982 and later joined the Kanagawa Institute of Technology, Japan, in 1997 where he is currently a professor. For over 30 years, he has been researching various aspects of images such as image processing, image communication, and image input/output systems in which 3D image displays and printing are included.*

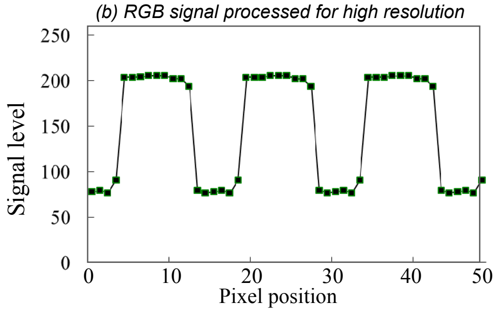
*Kazutake Uehira received his B.S. and M.S. in Electronics in 1979 and 1981 and his Ph.D. in 1994 all from the University of Osaka Prefecture, Japan. He joined NTT Electrical Communication Laboratories in Tokyo, Japan, in 1981. Since then, he has been engaged in research and development on image acquisition technologies, display systems, and high-reality video communication systems. In 2001, he joined Kanagawa Institute of Technology, Japan, as a professor.*



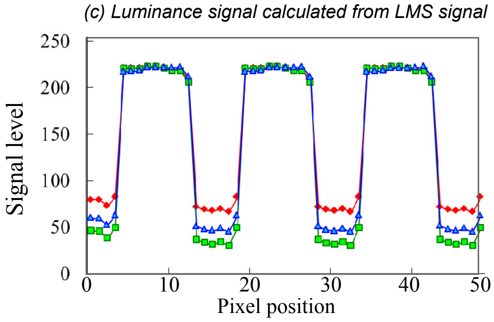

*(a) Luminance signal calculated from RGB signal*




*(b) RGB signal processed for high resolution*

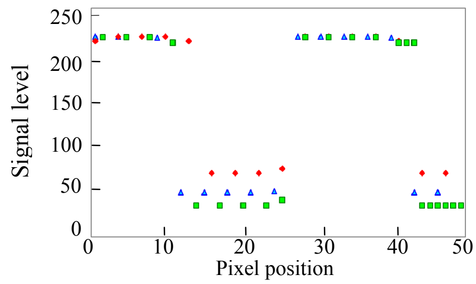



*(c) Luminance signal calculated from LMS signal*

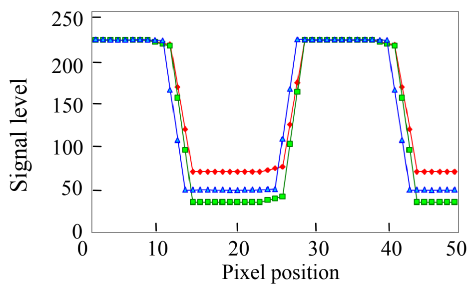



*(d) LMS signal processed for high resolution*

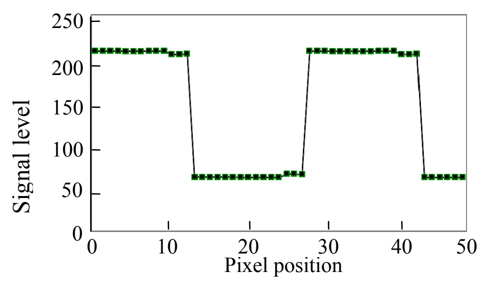
***Figure 4*** *Simulation results on effect of difference of color filter.*



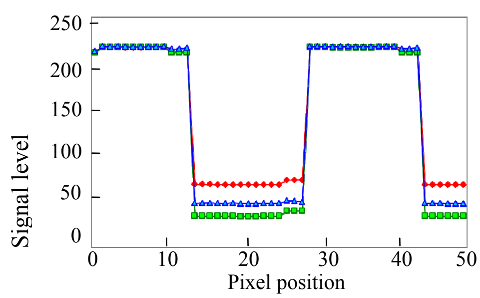

*(a) Original LMS component signal*




*(b) Signals produced by interpolation*




*(c) Corrected luminance signals H-K*




*(d) LMS color component signal produced using H-K*

***Figure 5*** *Results for the simulation on the signal around the pattern edge*