프로젝션 TV에서의 광학적 왜곡 보정 알고리즘

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Digital Video Warping for Convergence of Projection TV Receivers

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ABSTRACT

In this paper, we present a novel method to solve the inevitable RGB beam mismatch problem in projection TV receivers. Conventional methods solve the mismatch problem by directly controlling the cathode ray tube (CRT) using the convergence yoke (CY). Unlike conventional methods, the proposed method is based on digital video processing using image warping techniques. Firstly RGB beam projection paths are mathematically modeled. Then based on the modeling, the input video signal to CRT is pre-warped so that RGB beams are landed at the same point on the screen. Since the proposed method is based on a digital video processing instead of using CY, it can outperform the conventional method in terms of quality and cost. The experimental results with a real 60' projection TV demonstrate that the proposed method indeed produces converged images on the projection TV screen.

I. INTRODUCTION

Recently the rise in a standard of living has increased the demand for high quality TV receivers of a large screen size. A projection TV with a magnification lens and a reflection mirror has been widely popular for relatively low prices. The projection TV, however, comes with inevitable RGB beam mismatch problem which badly degrades the image quality due to the different placement of red, green and blue (RGB) cathode ray tubes (CRTs), as shown in Fig. 1.

To guarantee the RGB convergence, conventional methods are based on directly controlling CRT by adopting additional convergence yoke (CY) [1][2] as shown in Fig. 2(a). Since the CY-based method uses analog circuit devices, it is difficult to implement and control. In addition, aging of the analog devices in CY causes the performance degradation as time goes.

In this paper, we present a novel approach based on a digital video warping technique instead of CY as shown in Fig. 2(b). Firstly RGB beam projection paths are mathematically modeled. Then based on the modeling for the beam projection paths, the image warping process is performed before entering CRT so that RGB beams are landed at the same point on the screen. It means that the input video signals, which are stored in the frame memory, are warped in advance considering the RGB beam projection paths. To give a better insight of the proposed approach, let the coordinate of input video signal be (x, y) and the system function of the existing beam projection path be $T(.)$. By performing the image warping process corresponding to $T^{-1}(.)$, the resulting coordinate on the screen through the warping process is given by

$$T[T^{-1}(x, y)] = (x, y). \tag{1}$$

Since the proposed method is based on a digital video processing instead of CY, it can outperform the conventional method in terms of quality and cost.

The rest of the paper is structured as follows. Section II describes the mathematical modeling of projection TV and the projection path. In Section III, the projection path estimation and the video warping process are described. In Section IV, the experimental results applied at a real 60' projection TV are shown for testing practical usefulness, and finally Section V gives conclusions.
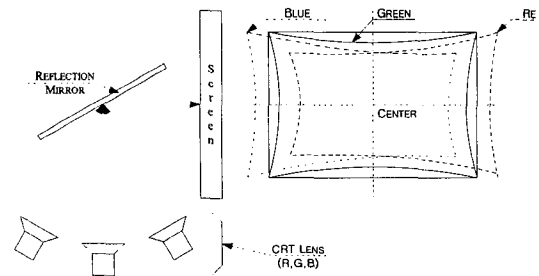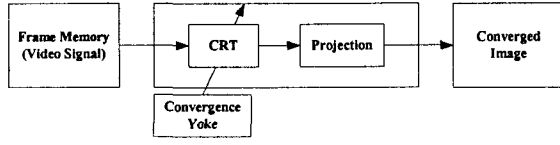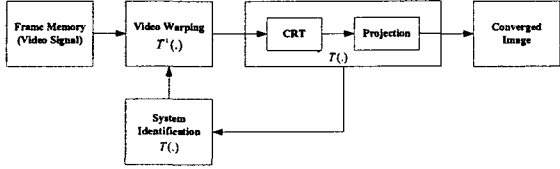

Fig. 1. RGB mis-convergence in projection TV

(a) The conventional method based on CY

(b) The proposed method based on digital video warping

Fig. 2. Conventional and proposed methods for convergence of projection TV receivers

II. PROJECTION TV SYSTEM MODELING

A. Overall System Model

The projection TV system can be modeled by 2-D spatial transformation. Assume that the input coordinate of the system should be (u,v) and the output coordinate be (x,y). Let spatial transformation function $T_x(.)$ and $T_y(.)$, then the output coordinate is given by

$$x = T_x(u,v) + n_x = x_o + n_x \qquad (2.a)$$

$$y = T_y(u,v) + n_y = y_o + n_y \qquad (2.b)$$

where n_x and n_y are zero-mean white measurement noise.

The block diagram for the overall system identification is shown in Fig. 3. The system identification problem of projection TV is identical to find the coefficients of 2-D spatial transformation function, that is $T_x(.)$ and $T_y(.)$. Let $\hat{T}(.)$ be the estimated overall system function and if the estimate is identical to the original system function, that is $\hat{T}(.) = T(.)$, the output coordinate of the overall system becomes

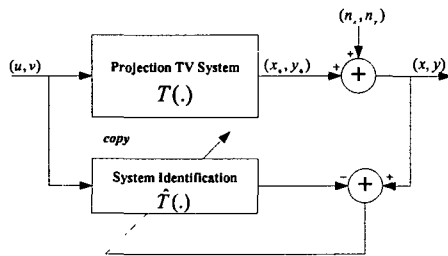$$T((\hat{T}^{-1}(u,v)) = T(T^{-1}(u,v)) = (u,v) . \qquad (3)$$

Fig. 3. Overall system identification model

B. Image Projection Path Modeling

The beam paths in the projection TV are separable into two components: pincushion and keystone. The pincushion comes from using CRT and a magnifying lens. Fig. 4(a) shows a radially distorted image by the pincushion. Then the image through CRT and lens is projected on a screen by reflection mirror. Since the paths of reflection are not perpendicular to the screen, a rectangular image is transformed to any quadrilateral one. This phenomenon is called keystone as shown in Fig. 4(b). In this paper, the whole projection TV system is modeled by these two components.

The feature of the pincushion is radial so that the displacement is increased as it goes from the center of an image. Let (C_x, C_y) be the center of the image coordinate. The modeling equation this radial property is given by

$$x = u + \bar{u} \cdot (P_o^x + P_1^x \cdot r + P_2^x \cdot r^2 + P_3^x \cdot r^3 + \cdots)$$
$$y = v + \bar{v} \cdot (P_o^y + P_1^y \cdot r + P_2^y \cdot r^2 + P_3^y \cdot r^3 + \cdots) \qquad (4)$$

where $\bar{u} = u - C_x$, $\bar{v} = v - C_y$ and $r = \sqrt{\bar{u}^2 + \bar{v}^2}$. The coefficient, P_o, determines the scaling of the displayed image and the others determine the curvilinear displacement.

The keystone, due to the reflection mirror, has a distinguishing feature, which the straightness of the original image is preserved after that distortion as shown in Fig. 4(b). Thus, the perspective transform matrix, which can specify the general quadrilateral-to-quadrilateral transformation, can be used for the modeling [3]. Let (u,v), (x',y',z') and (x,y) be the coordinates of the original image, a temporary image, the distorted image, respectively. Then the keystone modeling equation is represented by

$$\begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} = K \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} \quad \text{where} \quad K = \begin{bmatrix} k_{11} & k_{12} & k_{13} \\ k_{21} & k_{22} & k_{23} \\ k_{31} & k_{32} & 1 \end{bmatrix} \qquad (5)$$

and

$$x = x'/z', \quad y = y'/z' . \qquad (6)$$

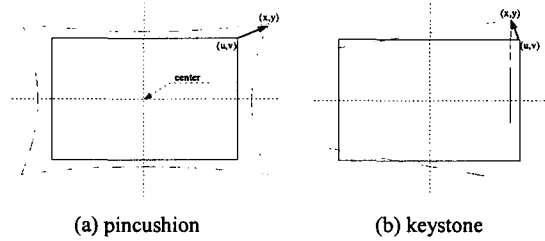(a) pincushion   (b) keystone

Fig. 4. Image distortion by pincushion and the keystone

III. PROPOSED WARPING METHOD

A. Projection Path Estimation

To estimate a projection path, the coordinate information of the reference and the observed images is required. The key idea of the parameter estimation is to use the distinguishing property of the pincushion and the keystone; the former is radial but the latter is uniform at the whole screen. The initial keystone parameter is measured in the central part of the screen, where the pincushion distortion is small compared with the side of the screen. Then, the initial pincushion parameter is measured with the keystone distortion removed using the initial keystone parameter.

However, since the whole projection system is combined with the keystone and the pincushion, it is hard to find the model parameters corresponding to each phenomenon. Thus a reasonable new iterative method for the parameter estimation is required. Each parameter is updated iteratively while the other is nearly removed until both are vanished. The block diagram for parameter estimation is given in Fig. 5.
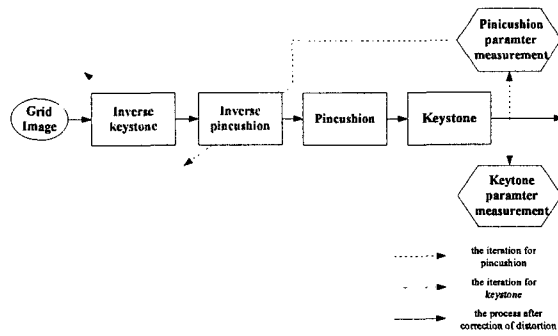

Fig. 5. The block diagram for parameter estimation

B. Video Warping

Let (u,v) be the coordinate of a input image stored in frame memory and $(\tilde{u},\tilde{v})$ be that of warped image and $\hat{T}(.)$ be the estimated system function of the overall projection TV system. Since the warped image passed the inverse of the estimated system, we obtain

$$(\tilde{u},\tilde{v}) = \hat{T}^{-1}(u,v). \tag{7}$$

To form the warped image, the pixel value at integer point $(\tilde{u},\tilde{v})$ is required, which can be obtained by using the input pixel value, $I_w(.)$. Because the (u,v) , however, corresponding to integer $(\tilde{u},\tilde{v})$ is generally non-integer point and $I_w(.)$ is defined only at integer points, the interpolation process is required [6]. This permits pixel values to be evaluated at arbitrary positions, not just those defined at the integral points. Let $\hat{I}_w(.)$ be the value of the point to be interpolated. Then $\hat{I}_w(.)$ is equal to the sum of the values of the near discrete point weighted by the corresponding values,

which is represented by

$$\hat{I}_w(u,v) = \sum_{i=-1}^{1}\sum_{j=-1}^{1} w_{ij} I_w(\text{int}(u)+i, \text{int}(v)+j) \tag{8}$$

where $\text{int}(.)$ means the integer part and w_{ij} means the interpolation weight. The pixel value of warped image is represented by

$$I_w(\tilde{u},\tilde{v}) = \hat{I}_w(u,v) . \tag{9}$$

Using these equations, each RGB image is warped respectively.

IV. EXPERIMENTAL RESULTS

In order to evaluate the performance of the proposed method 640×480 RGB grid images and a real color image were used in a real 60' projection TV. Because the warping process treats the source image, it is required to match the coordinates on the screen with the ones of the source image. For this purpose, the magnification rate, which determines how long on the screen a pixel on the source image is, should be measured. The estimated keystone and pincushion parameters for the real 60' projection TV are shown in Table 1 and 2, respectively.

Using these parameters, the grid image is warped with bilinear interpolation. Fig. 6(a) shows the RGB mis-convergence, which badly degrades the image quality, but the corrected image in Fig. 6(b) shows a successful RGB convergence. The experiments of real image are presented in Fig. 7.

Table 1. Measured keystone parameters

	Keystone parameter
Red	$K_r = \begin{bmatrix} 1.212089 & 2.2206813e-2 & -24.93991 \\ 7.2265073e-2 & 1.1243702 & -26.06495 \\ 3.116043e-4 & 4.88899e-5 & 1.0 \end{bmatrix}$
Green	$K_{green} = \begin{bmatrix} 9.87062824e-1 & 1.7414907e-2 & 5.606558e-1 \\ -8.26247655e-3 & 1.022124 & -2.2104813 \\ -3.8927750e-5 & 5.974696e-5 & 1.0 \end{bmatrix}$
Blue	$K_{blue} = \begin{bmatrix} 8.1693663e-1 & 1.654162e-2 & 18.79025 \\ -6.9437760e-2 & 9.4823177e-1 & 15.789 \\ -2.8214268e-4 & 4.5355239e-5 & 1.0 \end{bmatrix}$

Table 2. Measured pincushion parameters

	Pincushion parameter
Red	$\begin{cases} P_r^x = -0.084, & P_r^y = 6.87e-7 & (u<0) \\ P_r^x = -0.076, & P_r^y = 6.93e-7 & (u>0) \end{cases}$ $P_r^x = -0.15, \quad P_r^y = 2.295e-6$
Green	$P_g^x = -0.07, \quad P_g^y = 6.975e-7$ $P_g^x = -0.15, \quad P_g^y = 2.295e-6$
Blue	$P_b^x = -0.0411, \quad P_b^y = 7.192e-7$

(a) Grid image with RGB mis-convergence

(b) Grid image with RGB convergence

Fig. 6. Grid image test for RGB convergence

(a) Real test image with RGB mis-convergence

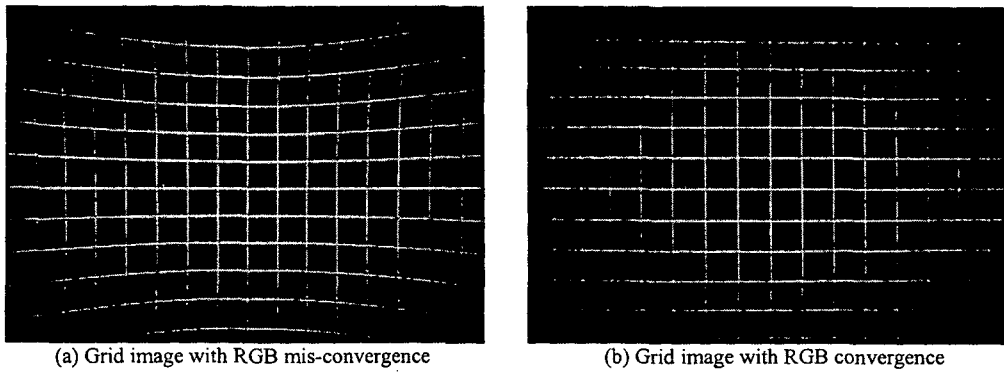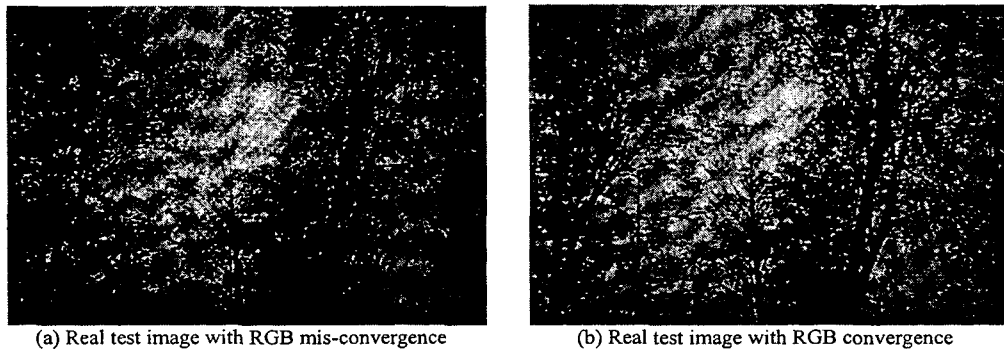(b) Real test image with RGB convergence

Fig. 7. Real test image for RGB convergence

V. CONCLUSION

We have presented a novel method for convergence in projection TV receivers. The method is performed by warping the input video signal based on the each RGB projection beam path modeling so that RGB beams are landed at the same point on the screen. Since the model parameters are estimated on the production line, the complexity in real-time process depends only on-line video warping part, which can be implemented easily and cost-efficiently. Since the proposed method is based on digital image processing, it guarantees permanently stable performance unlike the conventional methods. Another excellent feature of the proposed method is that it is applicable to not only the projection TV but also other display systems.

ACKNOWLEDGEMENT

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