3CCD INTERPOLATION USING SELECTIVE PROJECTION

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ABSTRACT

Emerging of HDTV accelerates evolution of high-resolution imaging system. A 3CCD digital camera system has been developed for higher resolution than a CCD imaging has. From the pixel correlation caused by half-pixel shift of the green channel, we can interpolate pixels and get four times higher resolution of color image. The proposed method involves three projection operators. The first is to reduce aliasing of image regions by selective projection in subband channels. The second projection makes inverse of MTF which generates blurring over the entire image. The last operator works for fast convergence. From the experimental result, the proposed algorithm shows suppression of jagging effects and restoration of aliased image regions. It is experimentally shown that the projection process converges and is almost finished at the first iteration.

1. INTRODUCTION

A 3CCD(three-charge-coupled-device) digital camera system is an emerging device for High-Definition video imaging, and it is expected that 3CCD video cameras will replace the current CCD-based video cameras which provide comparatively lower resolution than display device can support[1]. In order to acquire higher resolution image than the effective number of pixels, a new innovation is introduced. It applies a spatial half-pixel shift in diagonal direction between the green channel and the red/blue channel as shown Fig.1. To reconstruct a full-color image from the initial samples, two missing pixels and color components in four new pixels are generated from neighboring pixel values. Exploiting spatial correlation, Yuichi proposes to estimate the missing values by directional characteristics which are based on the gradient and which preserve the edges[2]. However, as we will show in this paper, the method has jagging effects and notable aliasing in high frequency regions.

In this paper, we propose an iterative interpolation algorithm which well preserve edges on not only the horizontal and vertical but also the diagonal direction. Furthermore, it restores the reconstructed signals from their neighbors in order to avoid aliasing. We also argue that the modulation transfer function(MTF) needs to be considered so that the blurring caused by the imaging device spreads out during the interpolation process. We organize this paper as follows. First, we develop an iterative interpolation scheme and define projection operators in Section 2. Its experimental performance and comparisons with other method are given in Section 3. The conclusion of this paper is given in Section 4.

2. INTERPOLATION USING SELECTIVE PROJECTION

To interpolate the pixels between the acquired pixels, this paper proposes a projection based interpolation approach, which considers not only the reconstruction of pixels from neighboring pixels but also the deblurring caused by MTF in the acquisition system of a video camera.

This paper starts from several observations of an acquisition device. The first is the progressive scan process in which the proposed algorithm goes through the entire frame. The sampling frequencies for the three channels are same, and the aliasing caused by the sampling rate when it is less than the bandwidth of the original signal is unknown and irregular.

From these observations, the constraint sets which manipulate the spatial and subband correlations are defined. The defined constraint sets are convex and the intersection of all the constraint sets is also nonempty convex set[3].

2.1. Projection Operators

The projection method is used for finding a feasible solution that satisfies the constraints. The constraint sets have to be convex and have one intersection so that they converge to the intersection iteratively. Additionally, in order to find definitive solution, it needs to be as small as possible. For the 3CCD interpolation problem, we propose three projection operators, two of them are consistent with the constraint sets and one aims at fast convergence.

2.1.1. Subband Reconstruction

Fist we assume that the subband channels are highly correlated with each other, which provides a basis for solving the interpolation problem. After selectively applying the reconstruction operation to the image regions apt to artifacts, it is able to successfully restore the signal with reduced aliasing which is sensitive to human eyes. We define undecimated analysis and synthesis operations for obtaining four subband channels as follows[4]:

$$\begin{aligned} S_{LL}(\vec{n}) = \mathcal{D}_1 S(\vec{n}), \quad S_{LH}(\vec{n}) = \mathcal{D}_2 S(\vec{n}) \\ S_{HL}(\vec{n}) = \mathcal{D}_3 S(\vec{n}), \quad S_{HH}(\vec{n}) = \mathcal{D}_4 S(\vec{n}) \end{aligned} \tag{1}$$

$$\begin{aligned} S(\vec{n}) \quad &= \mathcal{R}_1 S_{LL}(\vec{n}) + \mathcal{R}_2 S_{LH}(\vec{n}) + \\ &\mathcal{R}_3 S_{HL}(\vec{n}) + \mathcal{R}_4 S_{HH}(\vec{n}) \end{aligned} \tag{2}$$

where $S_{LL}, S_{LH}, S_{HL}, S_{HH}$ denotes the four subbands.
And we determine the aliased region from the color channels by using a Laplacian operator[5] which gives a satisfactory result as follows

$$F_S(\vec{n}) = S(\vec{n}) * * h(\vec{n}) \tag{3}$$

$$\text{where} \quad h(\vec{n}) = \frac{1}{11} \begin{bmatrix} 1 & 9 & 1 \\ 9 & -40 & 9 \\ 1 & 9 & 1 \end{bmatrix}$$

When $F_S(\vec{n})$ is less than a threshold θ in magnitude, we decide that the pixel is in the aliased region. It has to be restored by applying the projection operator for the subband values at the same place.

Now we can write the projection operator of restoring the pixel in aliased region as follows.

$$P_r[S(\vec{n})] = (\mathcal{R}_1\mathcal{D}_1)S(\vec{n}) + \sum_{k=2}^{4}(\mathcal{R}_k\mathcal{D}'_k)S(\vec{n}) \tag{4}$$

In (4), $\mathcal{D}'_K S(\vec{n})$ has to be changed in three channels so that the value filtered by Laplacian operator is less than θ. We write $\mathcal{D}'_k S(\vec{n})$ in (5).

$$\mathcal{D}'_k S(\vec{n}) = \begin{cases} \mathcal{D}_k S(\vec{n}) & F_s < \theta \\ \mathcal{D}_k S(\vec{n}) - s(S(\vec{n}) - (\mathcal{D}_k R(\vec{n}))) \cdot \eta & F_R < F_G, F_B \\ \mathcal{D}_k S(\vec{n}) - s(S(\vec{n}) - (\mathcal{D}_k G(\vec{n}))) \cdot \eta & F_G < F_B \\ \mathcal{D}_k S(\vec{n}) - s(S(\vec{n}) - (\mathcal{D}_k B(\vec{n}))) \cdot \eta & \text{otherwise} \end{cases} \tag{5}$$

where $s(\cdot)$ is a signum function.
η is a priori bound.

2.1.2. *Inverse MTF*

The response of a linear imaging system is characterized in MTF (Modulation Transfer Function) that determines the overall sharpness quality[6]. Deconvolving the MTF which models a significant blur to the acquired signal, we can get a sharpened image. Furthermore, in reconstructing the aliased region the blurring spreads over the signal. Therefore during the reconstruction process, inverse filtering of the MTF model needs to be considered. In this paper we process the inverse function only for Y component in YCbCr domain in order to avoid color noise. We define the $r^{(y)}(\vec{n})$ as residual.

$$r^{(y)}(\vec{n}) = y_0(\vec{n}) - y(\vec{n}) ** h_M(\vec{n}) \tag{6}$$

where $y_0(\vec{n})$ the signal at initial iterate.
$h_M(\vec{n})$ is the impulse response of MTF.

If the absolute value of the residual is less than the threshold δ, the value $y(\vec{n})$ in YCbCr domain does not change. Referring to (6), we can write the convex set of the inverse MTF as follows.

$$C_I = \left\{ y(\vec{n}) \| \;\; r^{(y)}(\vec{n}) \;\; \leq \delta \right\} \tag{7}$$

where δ is a bound for suppression artifact. The projection operator P_I onto C_I is defined by

$$P_I[y(\vec{n})] = \begin{cases} y(\vec{n}) + \frac{\left(r^{(y)}(\vec{n}) - \delta\right) \cdot h_M}{\|h_M\|^2} & r^{(y)}(\vec{n}) > \delta \\ y(\vec{n}) - \frac{\left(r^{(y)}(\vec{n}) - \delta\right) \cdot h_M}{\|h_M\|^2} & r^{(y)}(\vec{n}) < \delta \\ y(\vec{n}) & otherwise \end{cases} \tag{8}$$

2.1.3. *Bound on Pixel Value*

Additionally we propose another projection operator which makes a bound on the pixel value for the color channels for fast convergence. It is defined by

$$P_B[S(\vec{n})] = \begin{cases} 0 & S(\vec{n}) < 0 \\ S(\vec{n}) & 0 \leq S(\vec{n}) \leq \alpha \\ \alpha & \alpha < S(\vec{n}) \end{cases} \tag{9}$$

where α denotes the maximum magnitude bound.

2.2. Algorithm Flow

When the image sequence is obtained from a 3CCD system, all three color pixels are separated into 4 new pixels, locate the red and blue components at the upper-left region, the green component at the lower-right region. First we initially interpolate by bilinear or bicubic interpolation methods. Then decompose all three channels with (1), make change on the three subbands of three color channels by using the reconstruction projection operator, synthesis three color channels back. And update the Y component of the color channels by using the projection operator (8), suppress magnitude of three channels by (9). Finally go back to the decompose step and repeat until a certain condition is satisfied.

3. EXPERIMENTAL RESULTS

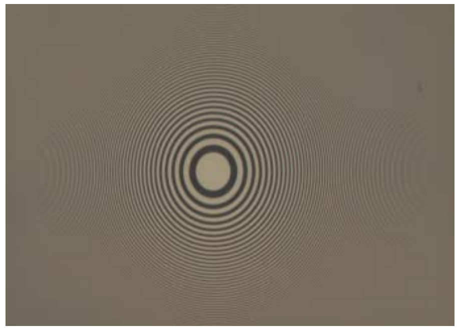
For experimental evaluation of the performance of the proposed algorithm, we use the 'Cirle Chart' obtained under 5100K illuminant. Note that each pixel has 10 bit resolutions, so α in (9) is 1024. The coefficient $\theta = 150$ and $\eta = 20$ for (5) and $\delta = 2$ for (8) are selected. We make a blur model for MTF as follows.

$$h_M(\vec{n}) = \frac{1}{16}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 8 & 1 \\ 1 & 1 & 1 \end{bmatrix} \tag{10}$$

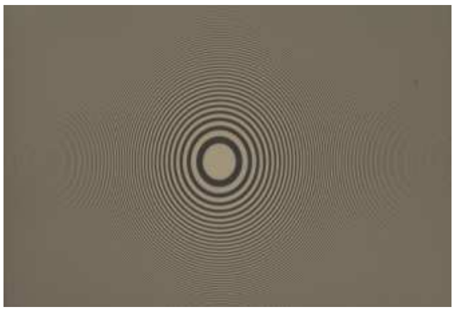
To illustrate the suppression of jagging effect and restoration of aliased region, we compare the result from 8th iteration with the result of bilinear interpolation and the method in [2]. Fig.2 shows the result of the methods. From Fig.3 the proposed algorithm removes the jagging effects successfully. And we also see the result of the restoration of aliased region on the right side of the 'Circle Chart' image as shown in Fig.4. Table1 lists the mean squared differences of three channels of the result images as the iteration increases. And it is experimentally shown that most of the processing is finished at the first iteration. It is also verified that the convex sets are well defined so that there exists one intersection and it's region is small enough.

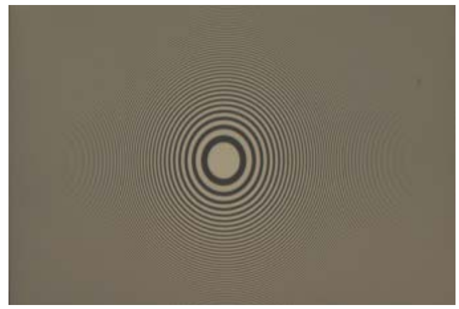
4. CONCLUSION

In this paper, we have presented a 3CCD interpolation algorithm with jagging effect suppression and restoration of aliased image region using selective projection. Although 3CCD imaging system can be used without any interpolation process, by applying it we can get an image with hight resolution from the truth that the pixels are highly correlated with each other. At the first step, the initial pixel values are divided into new four pixels and relocated. After interpolating the initially reconstructed image by bilinear or bicubic method, it processes three projection operators and repeats them iteratively until a certain condition is satisfied. One of the projection operators is to change the pixel values selected by a Laplacian Operator in three subbands channels. Another projection operator is to restore the Y component of the degraded image caused by MTF of imaging system in YCbCr Domain. Finally the last projection operator suppresses the pixel values into the magnitude bound. Using the operators of subband reconstruction and inverse MTF, we can generate better high-resolution image from aliased signal and remove the jagging effect which can happen on the edge of diagonal direction. The convergence of the algorithm is also shown experimentally.



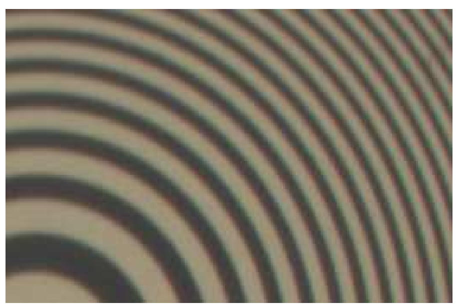
(a) Bilinear Interpolation



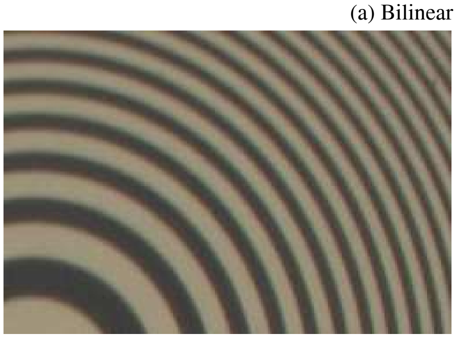


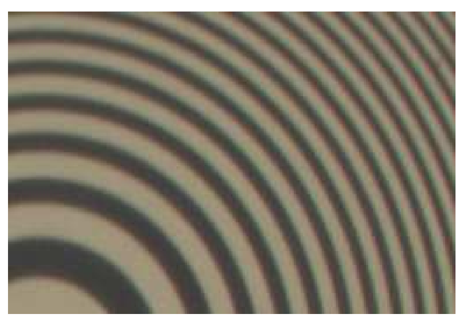
(b) Method in [2] (c) Proposed Algorithm

Fig. 2. Interpolation result of Circle Chart



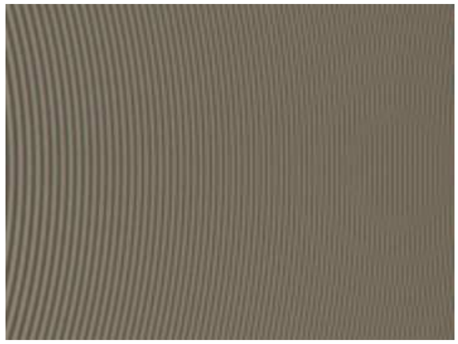
(a) Bilinear Interpolation



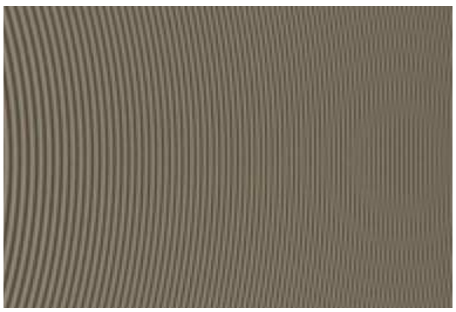


(b) Method in [2] (c) Proposed Algorithm

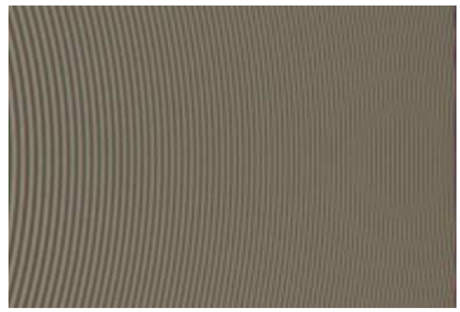
Fig. 3. Diagonal edge in Circle Chart



(a) Bilinear Interpolation



(b) Method in [2]



(c) Proposed Algorithm

Fig. 4. Right side in Circle Chart

Iteration	R	G	B
1	105.404	38.674	174.132
2	0.479	0.434	0.274
3	0.369	0.331	0.199
4	0.287	0.253	0.146
5	0.224	0.195	0.112
6	0.176	0.151	0.090
7	0.140	0.093	0.061
8	0.090	0.074	0.050

Table 1. Mean Squared Difference between images processed by proposed algorithm

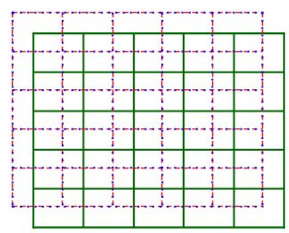


Fig. 1. Sampling lattice array of 3CCD

5. REFERENCES

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