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(54) **FILTERING CONTROL METHOD FOR IMPROVING IMAGE QUALITY OF BI-LINEAR INTERPOLATED IMAGE**

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(58) **Field of Classification Search** ..... **382/260, 382/261, 262, 263, 264, 298, 299, 300; 358/525; 345/3.3, 698**

See application file for complete search history.

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(57) **ABSTRACT**

The present invention relates to an interpolation method for enlarging a digital image or predicting a moving vector of a compressed image system as a sub-pixel unit when the image digitized through a CCD (Charge Coupled Device) camera ect. has a low resolution in a video phone or video conference or general digital video system, particularly the present invention can be adapted to a post processor of a compressed digital image in order to improve the image quality, and can be used for finding a moving vector of a moving picture compressed type, accordingly the present invention is capable of improving the image quality.

**11 Claims, 4 Drawing Sheets**

A	-7	81	-14	0	52	405	24	0	-13	-2	-14	0	0	0	0	0
B	-6	23	52	-12	-9	201	302	-12	-3	-5	-13	-6	0	0	0	0
C	-8	43	-16	0	99	382	-9	0	-3	38	-14	0	0	0	0	0
D	-10	38	-20	0	54	397	27	0	-7	49	-16	0	0	0	0	0
E	-13	33	-23	0	10	413	62	0	-12	59	-17	0	0	0	0	0
F	-12	26	-15	-3	-4	354	142	-5	-11	48	-4	-4	0	0	0	0
G	-10	17	-8	-7	-13	295	221	-9	-10	36	9	-9	0	0	0	0
H	-5	4	18	-11	-9	197	302	-9	-5	17	24	-11	0	0	0	0
I	-14	-6	-21	0	56	338	29	0	-2	99	-17	0	0	0	0	0
J	-10	-7	-24	-3	-5	344	145	-5	-12	88	7	-6	0	0	0	0
K	-4	-13	-16	-11	-10	194	301	-6	-6	39	60	-16	0	0	0	0
L	-12	-13	-9	0	53	363	26	0	1	111	-8	0	0	0	0	0
M	-9	-14	-11	0	19	356	67	0	-6	109	1	0	0	0	0	0
N	-9	-9	-14	-2	-9	261	195	-5	-9	74	45	-6	0	0	0	0
O	-12	-5	-13	-4	-5	174	282	-9	-5	42	79	-12	0	0	0	0
P	-6	-10	-8	0	19	219	18	0	37	271	6	0	-9	-16	-9	0
Q	-8	-9	-6	1	-11	193	76	-4	-7	243	83	-4	-4	-14	-14	-1
R	-1	-8	-11	-4	-8	102	156	-13	-8	142	206	-10	-1	-11	-15	-4
S	-4	-5	-3	0	23	153	-16	0	83	330	-13	0	-13	-16	-7	0
T	-3	-5	-4	0	6	151	0	0	45	338	15	0	-11	-9	-11	0
U	-2	-5	-5	0	-10	149	15	0	7	347	43	0	-9	-2	-16	0
V	-2	-4	-6	-1	-12	125	35	-4	-5	304	111	-4	-6	-3	-14	-2
W	-1	-4	-6	-1	-14	102	55	-8	-16	260	179	-9	-4	-4	-13	-4
X	-1	-4	-6	-2	-7	62	104	-12	-8	172	255	-11	-2	-9	-14	-5

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FIG. 1

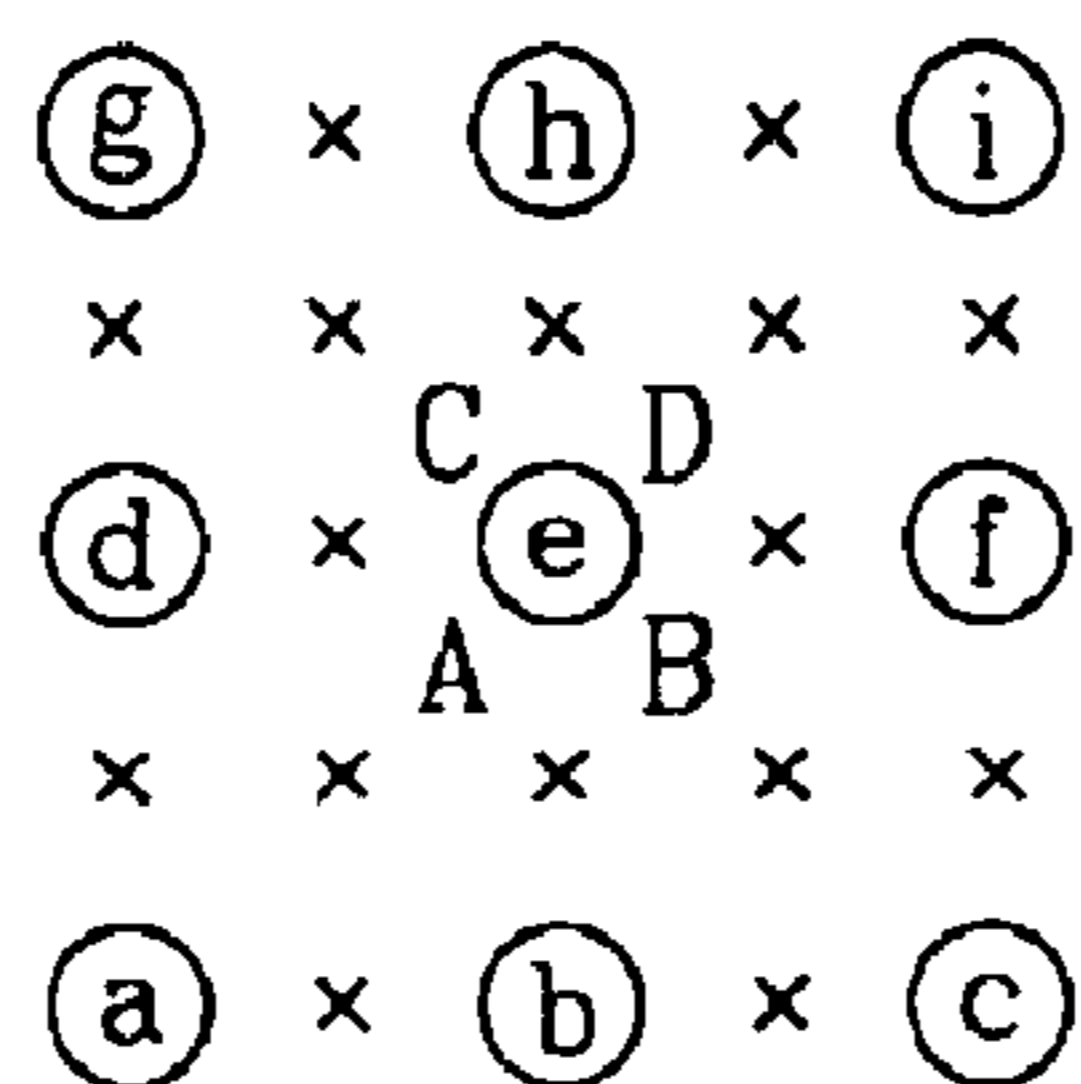


FIG. 2

$$\begin{bmatrix} A \\ B \\ C \\ D \end{bmatrix} = 1/512 \begin{bmatrix} 1 & 94 & -15 & 94 & 391 & -15 & -15 & -15 & -8 \\ -15 & 86 & -9 & -13 & 370 & 113 & -6 & -14 & -18 \\ -15 & -13 & -6 & 86 & 370 & -14 & 9 & 113 & -18 \\ 6 & -14 & -14 & -14 & 349 & 107 & -14 & 107 & 11 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \\ d \\ e \\ f \\ g \\ h \\ i \end{bmatrix}$$

FIG. 3

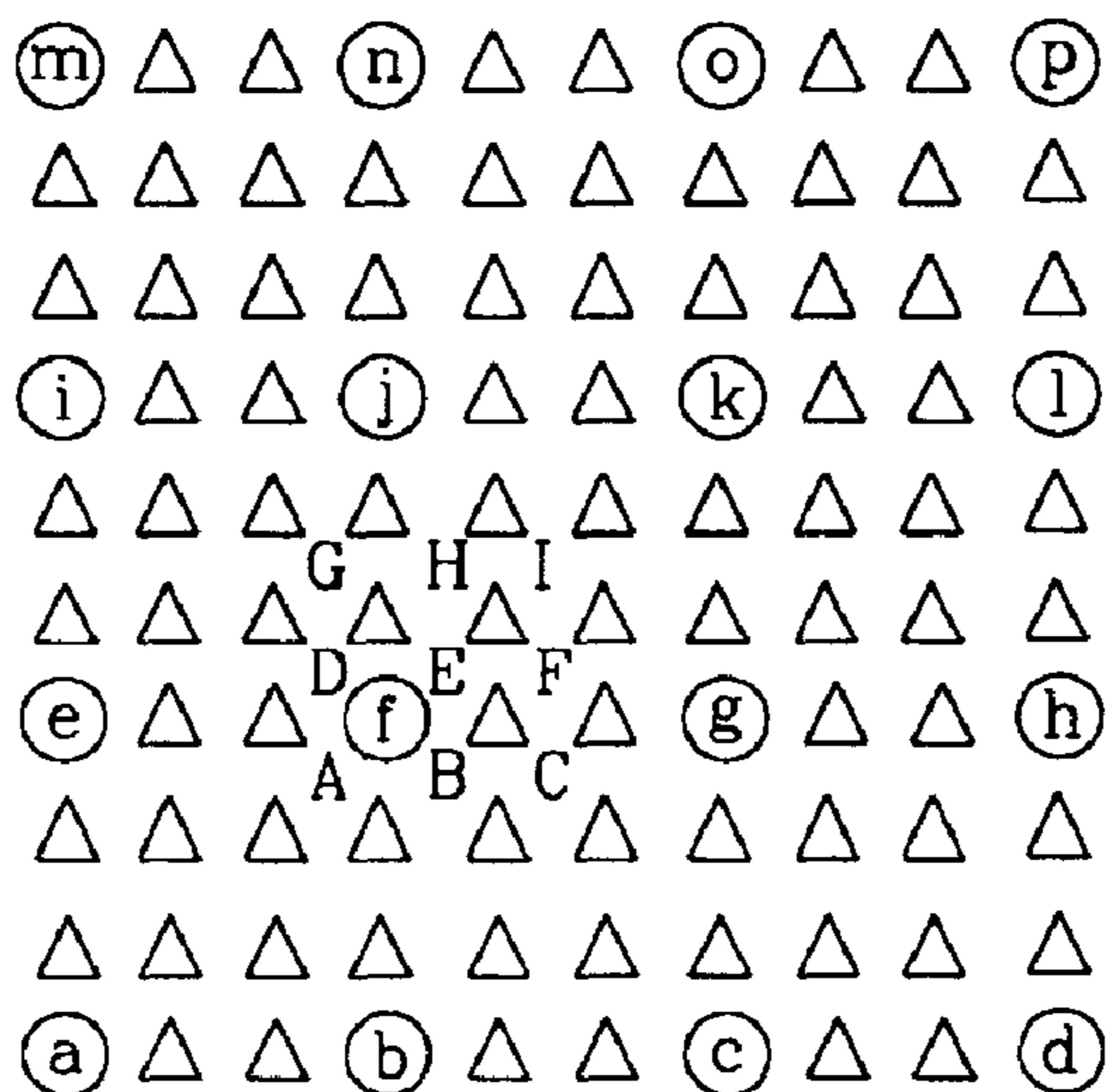
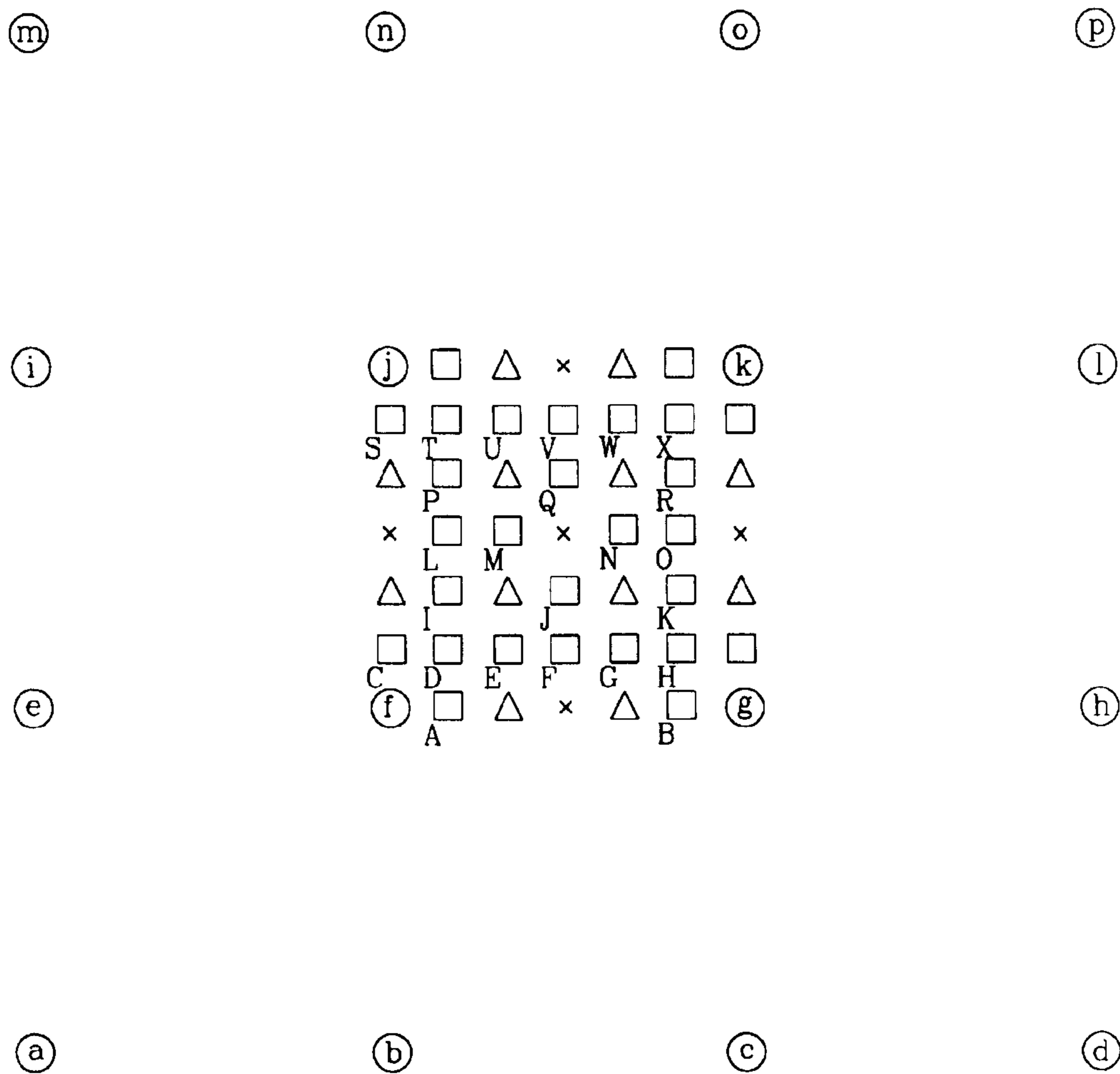


FIG. 4

$$\begin{bmatrix}
 \text{A} \\
 \text{B} \\
 \text{C} \\
 \text{D} \\
 \text{E} \\
 \text{F} \\
 \text{G} \\
 \text{H} \\
 \text{I}
 \end{bmatrix}
 = \frac{1}{512}
 \begin{bmatrix}
 -4 & 60 & -22 & 0 & 104 & 387 & -3 & 0 & -4 & 7 & -13 & 0 & 0 & 0 & 0 \\
 -15 & 71 & -22 & 0 & 11 & 422 & 63 & 0 & -11 & 12 & -19 & 0 & 0 & 0 & 0 \\
 -12 & 44 & 9 & -8 & -17 & 307 & 215 & -8 & -6 & 4 & -11 & -5 & 0 & 0 & 0 \\
 -16 & -8 & -16 & 0 & 103 & 372 & -3 & 0 & 9 & 91 & -20 & 0 & 0 & 0 & 0 \\
 -12 & -4 & -25 & 0 & 9 & 403 & 61 & 0 & -12 & 107 & -15 & 0 & 0 & 0 & 0 \\
 -8 & -9 & -23 & -5 & -19 & 284 & 229 & -10 & -13 & 69 & 29 & -12 & 0 & 0 & 0 \\
 -8 & -10 & -6 & 0 & 44 & 212 & -16 & 0 & 71 & 269 & -11 & 0 & -11 & -16 & -16 & 0 \\
 -4 & -9 & -10 & 0 & -6 & 226 & 52 & 0 & 2 & 272 & 22 & 0 & -6 & -15 & -12 & 0 \\
 -2 & -8 & -12 & -2 & -16 & 160 & 100 & -9 & -15 & 213 & 143 & -2 & -9 & -12 & -15 & -2
 \end{bmatrix}
 \begin{bmatrix}
 \text{a} \\
 \text{b} \\
 \text{c} \\
 \text{d} \\
 \text{e} \\
 \text{f} \\
 \text{g} \\
 \text{h} \\
 \text{i} \\
 \text{j} \\
 \text{k} \\
 \text{l} \\
 \text{m} \\
 \text{n} \\
 \text{o} \\
 \text{p}
 \end{bmatrix}$$

FIG. 5





**FILTERING CONTROL METHOD FOR  
IMPROVING IMAGE QUALITY OF  
BI-LINEAR INTERPOLATED IMAGE**

**Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.**

*CROSS-REFERENCE TO RELATED  
APPLICATIONS*

*NOTICE: More than one reissue application has been filed for the reissue of U.S. Pat. No. 6,803,954, including reissue application Ser. No. 12/424,927; U.S. patent application Ser. No. 12/024,408, which is a divisional reissue of U.S. Pat. No. 6,803,954; and U.S. patent application Ser. No. 11/546,484, which is a reissue of U.S. Pat. No. 6,803,954. Accordingly, this application is a continuation application of U.S. patent application Ser. No. 11/546,484, filed Oct. 12, 2006, now U.S. Pat. No. Re. 42,045, which is a reissue of U.S. application Ser. No. 09/692,156, filed Oct. 20, 2000, now U.S. Pat. No. 6,803,954, which claims the benefit of a foreign priority application filed in Korea as Serial No. 1999/45805 on Oct. 21, 1999. The disclosures of the prior applications are considered part of (and are incorporated by reference in) the disclosure of this application.*

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an interpolation method adapted to enlargement of a low resolution image when the image digitized through a CCD (Charged-Coupled Device) has the low resolution, in particular to a filtering control method for improving the image quality of a bi-linear interpolated image which is capable of restoring a requested interpolated high resolution image from a low resolution image by finding a coefficient of a two-dimensional filter on the basis of a regularization image restoration method.

2. Description of the Prior Art

In the conventional technology, a still picture or a moving picture has or transmits a low resolution image because it can not physically satisfy a sensor having the low resolution or a nyquist value.

In addition, a compressed moving picture has or transmits the low resolution image due to its bit value problem.

For example, when the compressed moving picture having the low bit value is transmitted to a receiver and the receiver enlarges the transmitted moving picture, the resolution of the transmitted moving picture lowers due to a degradation phenomenon ect.

Accordingly, a method for getting a high resolution image from a low resolution image is required.

In the meantime, the method for getting the high resolution image from the low resolution image is largely divided into an image expansion type method and an image enhancement type method.

First, the image expansion type method converts the size of the low resolution image into a requested size. The bi-linear interpolation method, a zero order expansion method, and a cubic spline method are comprised in the image expansion type method.

However, as described above, the image expansion type method has an image visibility lowering problem because when the image is interpolation-restored by the above-men-

tioned method such as the bi-linear interpolation method, zero order hold expansion method, cubic spline method, the outlines of the image is over-blurred.

Meanwhile, the image enhancement type method comprises many methods, but the image enhancement type method causes a computational complexity, accordingly the method is not suited to a real-time processing due to the its computational complexity.

In addition, when the image enhancement type method is used for getting the high resolution image from the low resolution image, setting of each parameter is not adaptable.

For example, there is a POCS (Projection Onto Convex Set) method for increasing the resolution of an image. In the POCS method, in use of time region information, it is assumed as correlation between the images is uniformly same, but actually the correlation between the images is not uniform.

In addition, there is a mapping method for mapping a non-uniform sample of the low resolution image into a uniform sample of the high resolution image by using moving information and segmentation information of the image. However, the mapping method has the computational complexity problem, accordingly the mapping method is not suited to the real-time image data processing of the image processing system.

SUMMARY OF THE INVENTION

The object of the present invention is to provide a filtering control method for improving the image quality of a bi-linear interpolated image which is capable of improving the image quality of the interpolated image by using an interpolation method considering a real-time processing, a computational complexity and an efficiency when the digital video system seeks the interpolated image from the low resolution image.

The other object of the present invention is to provide the filtering control method for improving the image quality of the bi-linear interpolated image which is capable of finding a two-dimensional filter coefficient for getting the interpolated image from the low resolution image on the basis of a regularization image restoration method.

The other object of the present invention is to provide the filtering control method for improving the image quality of the bi-linear interpolated image which can approximate and find a PSF (Point Spread Function) for the bi-linear interpolated image from a modeling of the degraded image in the frequency region.

The other object of the present invention is to provide the filtering control method for improving the image quality of the bi-linear interpolated image which is capable of performing a real-time adaptive processing by finding a filter coefficient from the bi-linear interpolated image and approximated PSF.

In the present invention, in order to find a filter coefficient for finding the interpolated image from the low resolution image on the basis of the regularization image restoration method, when  $H$  is the PSF (Point Spread Function),  $f$  is a requested high resolution image,  $Z$  is the low resolution image,  $g$  is the high resolution image gotten from the bi-linear interpolation method, an added function  $M(f) = \|g - Hf\|^2 + \alpha \|Cf\|^2$  for finding the PSF( $H$ ) from an equation  $g = Bz = Hf + n$  ( $B, H$  are bi-linear interpolated filters,  $n$  is a noise component generated by the assumed  $H$ ) is defined.

The filtering control method for improving the image quality of the bi-linear interpolated image can be implemented by

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finding the PSF(H) from the added function M(f) by using an equation

$$H(k, l) = \frac{G(k, l)}{F(k, l)}$$

The filtering control method for improving the image quality of the bi-linear interpolated image can be implemented by finding a PSF(P) of a f=Pg function by using an equation

$$P(k, l) = \frac{H^*(k, l)}{H^*(k, l)H(k, l) + C^*(k, l)C(k, l)}$$

after finding the PSF(H).

The filtering control method for improving the image quality of the bi-linear interpolated image can restore the requested high resolution image(f) by finding an added filter coefficient Q of the PSF(P) and interpolation filter B from the equation f=Pg=PBz=Qz.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates an image sample for getting a twice enlarged high resolution image according to the embodiment of the present invention.

FIG. 2 illustrates an interpolation filter coefficient for getting the twice enlarged image according to the embodiment of the present invention.

FIG. 3 illustrates an image sample for getting a three times enlarged high resolution image according to the other embodiment of the present invention.

FIG. 4 illustrates the interpolation filter coefficient for getting the three times enlarged image according to the other embodiment of the present invention.

FIG. 5 illustrates an image sample for getting a six times enlarged high resolution image according to the another embodiment of the present invention.

FIG. 6 illustrates the interpolation filter coefficient for getting the six times enlarged image according to the another embodiment of the present invention.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 1 illustrates an image sample for getting a twice enlarged high resolution image according to the embodiment of the present invention.

As depicted in FIG. 1, a~i illustrate low resolution pixels, A~D illustrate high resolution pixels. In addition, pixels depicted as 'x' illustrate pixels interpolated as twice by a twice interpolation filter coefficient.

FIG. 2 illustrates the interpolation filter coefficient for getting a twice enlarged image according to the embodiment of the present invention. In other words, the interpolation filter coefficient for interpolating the twice enlarged image of FIG. 1 is depicted in FIG. 2.

As depicted in FIG. 2, the high resolution image is gotten from the low resolution pixels a~i (3×3 pixels) inside of a circle of FIG. 1 by using the interpolation filter coefficient.

FIG. 3 illustrates an image sample for getting a three times enlarged high resolution image according to the other embodiment of the present invention.

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As depicted in FIG. 3, a~p illustrate the low resolution pixels, A~I illustrate the high resolution pixels using the filter according to the present invention.

FIG. 4 illustrates the interpolation filter coefficient for getting the three times enlarged image according to the other embodiment of the present invention.

As depicted in FIG. 4, three times enlarged pixels which are newly generated illustrated as triangles in FIG. 3 are gotten from the low resolution pixels a~p (4×4 pixels) by using the interpolation filter coefficient of FIG. 4.

FIG. 5 illustrates the image sample for getting a six times enlarged high resolution image according to the another embodiment of the present invention. In other words, it illustrates the image sample for getting the six times enlarged high resolution image from the twice and three times interpolation filter coefficients by using the bi-linear interpolation method.

As depicted in FIG. 5, pixels illustrated as a 'X' can be gotten by using the twice interpolation filter of FIG. 2, and pixels illustrated as a triangle can be gotten by using the three times interpolation filter coefficient of FIG. 4.

In addition, pixels illustrated as a quadrilateral can be gotten from the pixels generated by the twice and three times interpolation filter coefficients by using the bi-linear interpolation method.

FIG. 6 illustrates the interpolation filter coefficient for getting the six times enlarged image according to the another embodiment of the present invention. In other words, the interpolation filter coefficient for getting the six times enlarged image of FIG. 5 is depicted in FIG. 6.

Meanwhile, as depicted in FIG. 2, FIG. 4 and FIG. 6, the value found by using the interpolation filter coefficient of the present invention has an integer value.

In addition, a 9 bit shift is performed to the value calculated by the interpolation filter coefficient, accordingly there is no need to perform a floating point operation processing.

The twice, three times, six times interpolated images are depicted in FIG. 1~FIG. 6, however the present invention is not limited by that, it can be adapted freely to a certain interpolation value.

Hereinafter, the filtering control method for improving the image quality of the bi-linear interpolated image will be described in more detail.

First, a spatially invariant PSF (Point Spread Function) for finding the interpolation filter coefficient according to the each interpolation value can be easily analyzed and approximated in the frequency region, accordingly the spatially invariant PSF (Point Spread Function) is considered from the bi-linear interpolated image.

After that, when it is assumed as the low resolution image is z, high resolution image gotten by the bi-linear interpolation method is g, high resolution image to be restored is f, the relation between the each image can be described as below.

$$g=Bz=Hf+n \quad \text{[Equation 1]}$$

Herein, the B, H, n are the bi-linear interpolation filters, H is the spatially invariant PSF defining the relation between the original high resolution image and high resolution image gotten by the interpolation method, and the n is a noise component generated by the assumed H.



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Herein, when the noise component is neglected and a direct inverse is used in order to find the PSF(H), the PSF(H) can be described as below equation 2 in the frequency region.

$$H(k, l) = \frac{G(k, l)}{F(k, l)} \quad \text{[Equation 2]}$$

Herein, the H(k,l) is the component in the k,l frequency region of the PSF(H), the G (k,l) is the component in the k,l frequency region of the bi-linear interpolated image. In addition, the F (k,l) is the component in the k,l frequency region of the high resolution image.

Meanwhile, the high resolution image f to be restored is unknown, the PSF(H) can be gotten from the bi-linear interpolated high resolution image through a statistical processing after performing an under-sample processing of various images as various value.

Herein, the high resolution image is gotten by using the PSF(H) found from the direct inverse. In other words, there is a system stabilization problem because the high resolution image gotten from the PSF(H) by using the direct inverse is overshoot in the region where the k,l have '0' value (in general, high frequency region) in the frequency region, accordingly the regularization image restoration for improving the system stabilization is used to solve the problem.

The regularization image restoration method is used for restoring the image or finding a certain PSF, an added function M(f) for finding the PSF(H) by using the regularization image restoration method can be described as below equation 3.

$$M(f) = \|g - Hf\|^2 + \alpha \|Cf\|^2 \quad \text{[Equation 3]}$$

Herein, the first term of the right side of Equation 3 illustrates the credibility of the bi-linear interpolated image, the second term of the right side illustrates increase of the stability of the system by providing the mitigation to the restored image.

In addition, the  $\|\cdot\|$  means a norm, the  $\alpha$  is a regularization parameter for determining the credibility and mitigation of the original image. In addition, the C is the two-dimensional high frequency filter for determining the mitigation of the original image, in the present invention a two-dimensional Gaussian filter is used as the C.

When a gradient operator is adapted to Equation 3 in order to get the high resolution image, it can be described as below equation 4.

$$\square_j M(f) = -2H^T(g - Hf) + 2\alpha C^T C f = 0 \quad \text{[Equation 4]}$$

Herein, the T means a transpose of a matrix.

Meanwhile, conventionally a repetition method is used in order to get the high resolution image and regularization parameter, but it is not suited to the moving picture processing because the method causes lots of computational complexity.

Accordingly, in the present invention, the regularization parameter  $\alpha$  is fixed as '1', and the high resolution image f can be found as below equation 5.

$$f = \frac{H^T g}{(H^T H + C^T C)} = P g \quad \text{[Equation 5]}$$

When the PSF(P) is found by Equation 5, PSF(P)=H/(H<sup>T</sup>H+C<sup>T</sup>C) requires the lots of computational complexity for calculating an inverse matrix, however the PSF(P) in Equa-

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tion 5 is a block-circulant matrix, accordingly it can be easily calculated in the frequency region.

Accordingly, the PSF(P) can be found finally as below Equation 6.

$$P(k, l) = \frac{H^*(k, l)}{H^*(k, l)H(k, l) + C^*(k, l)C(k, l)} \quad \text{[Equation 6]}$$

Herein, the '\*' the means a complex-conjugate.

The PSF(P) can be found by using an IFT (Inverse Fourier Transform) from Equation 6.

The requested high resolution image f can be found as below Equation 7 by using the found PSF(P) and Equation 1.

$$f = P g = P B z = Q z \quad \text{[Equation 7]}$$

The PSF(P) is the spatially invariant function, the bi-linear interpolation filter B can be easily found by the conventional technology, accordingly the added filter coefficient Q of the PSF(P) and bi-linear interpolation filter B can be found.

Herein, in order to reduce the computational complexity, the number of a kernel of the PSF(P) is set in accordance with the up-sampling value.

When the up-sampling value is 2 in the present invention, the number of the kernel is limited as 3, when the up-sampling value is 3, the number of the kernel is limited as 4.

When the up-sampling value is 2, it can be used in an application segment for enlarging the size of the image as twice at a post processor of the compressed digital image and in finding of a sub-pixel moving vector in a H.263 moving picture compressed method.

In addition, when the up-sampling value is 3, it can be used in using of a 1/3 unit moving vector in a H.26L moving picture compressed method.

Herein, the H.263 and H.26L are moving picture compressed standards presented in the ITU-T (International Telecommunications Union-Telecommunication).

As described above, the present invention can be used for improving the image quality at the post processor of the compressed digital image by using the interpolation method for getting the interpolated high resolution image from the low resolution image when the resolution of the digital image lowers due to the low resolution image sensor.

In addition, the interpolation method of the present invention can improve the image quality by finding the moving vector of the moving picture compressed type.

What is claimed is:

**[1.]** A filtering control method for improving the image quality of a bi-linear interpolated image when recovering a high resolution image from a low resolution image, comprising:

restoring a requested high resolution image f by finding an added filter coefficient Q of a PSF(P) and a bi-linear interpolation filter B from an equation  $f = P g = P B z = Q z$ , wherein f is the high resolution image as requested, P is the PSF (Point Spread Function), g is the high resolution image found by the bi-linear interpolation method, and z is the low resolution image;

wherein the high resolution image f can be restored by performing an added function M(f) definition process for finding the PSF(H) from an equation  $g = B z = H f + n$ , wherein B, H are bilinear interpolation filters, and n is a noise component generated by the assumed H; and wherein the added function M(f) is defined as  $M(f) = \|g - Hf\|^2 + \alpha \|Cf\|^2$ , wherein  $\alpha$  is a regularization parameter,

and C is a two-dimensional high frequency filter for finding mitigation of the original image.]

[2. The filtering control method for improving the image quality of the bi-linear interpolated image according to claim 1, wherein the regularization parameter  $\alpha$  is fixed as '1' in order to reduce a computational complexity.]

[3. The filtering control method for improving image quality of the b-linear interpolated image according to claim 1, wherein a two-dimensional gaussian filter is used as the two-dimensional high frequency filter C in order to determine the mitigation of the original image.]

[4. A filtering control method for improving the image quality of a bi-linear interpolated image when recovering a high resolution image from a low resolution image, comprising:

restoring a requested high resolution image f by finding an added filter coefficient Q of a PSF(P) and a bi-linear interpolation filter B from an equation  $f=Pg=PBz=Qz$ , wherein f is the high resolution image as requested, P is the PSF (Point Spread Function), g is the high resolution image found by the bi-linear interpolation method, and z is the low resolution image;

wherein the high resolution image f can be restored by performing an added function M(f) definition process for finding the PSF(H) from an equation  $g=Bz=Hf+n$ , wherein B, H are bi-linear interpolation filters, and n is a noise component generated by the assumed H;

wherein the high resolution image f is restored by finding a PSF(P) of a  $f=Pg$  function after finding the PSF(H) from the added function M(f); and

wherein the PSF(H) is found by using an equation

$$H(k, l) = \frac{G(k, l)}{F(k, l)},$$

G(k,l) is the component in the k,l frequency region of the bi-linear interpolated image, and F(k,l) is the component in the k,l frequency region of the high resolution image.]

[5. A filtering control method for improving the image quality of a bi-linear interpolated image when recovering a high resolution image from a low resolution image, comprising:

restoring a requested high resolution image f by finding an added filter coefficient Q of a PSF(P) and a bi-linear interpolation filter B from an equation  $f=Pg=PBz=Qz$ , wherein f is the high resolution image as requested, P is the PSF (Point Spread Function), g is the high resolution image found by the bi-linear interpolation method, and z is the low resolution image;

wherein the PSF(P) can be found by getting an IFT (Inverse Fourier Transform) by an equation

$$P(k, l) = \frac{H^*(k, l)}{H^*(k, l)H(k, l) + C^*(k, l)C(k, l)}.$$

[6. The filtering control method for improving the image quality of the bi-linear interpolated image according to claim 5, wherein the number of a kernel of the PSF(P) is set in accordance with an up-sampling value of the image.]

[7. A filtering control method for improving the image quality of a bilinear interpolated image when recovering a high resolution image from a low resolution image, comprising:

defining an added function M(f) for finding a PSF(H) from an equation  $g=Bz=Hf+n$  (wherein B, H are bi-linear filters, n is a noise component generated by an assumed H when the H is a PSF (Point Spread Function), f is a requested high resolution image, z is a low resolution image, and g is a high resolution image gotten by the bi-linear interpolation method);

finding a PSF(P) of a  $f=Pg$  function after finding the PSF (H) from the defined added function M(f); and

restoring the requested high resolution image f by finding an added filter coefficient Q of the PSF(P) and interpolation filter B from the equation  $f=Pg=PBz=Qz$ ;

wherein the added function M(f) is defined as  $M(f)=\|g-Hf\|^2+\alpha\|Cf\|^2$ , wherein  $\alpha$  is a regularization parameter, and C is a two-dimensional high frequency filter for finding the mitigation of the original image.]

[8. The filtering control method for improving the image quality a of the bi-linear interpolated image according to claim 7, wherein the regularization parameter  $\alpha$  is fixed as '1' in order to reduce a computational complexity.]

[9. The filtering control method for improving image quality of the bi-linear interpolated image according to claim 7, wherein a two-dimensional gaussian filter is used as the two-dimensional high frequency filter C in order to determine the mitigation of the original image.]

[10. A filtering control method for improving the image quality of a bilinear interpolated image when recovering a high resolution image from a low resolution image, comprising:

defining an added function M(f) for finding a PSF(H) from an equation  $g=Bz=Hf+n$  (wherein B, H are bi-linear filters, n is a noise component generated by an assumed H when the H is a PST (Point Spread Function), f is a requested high resolution image, z is a low resolution image, and g is a high resolution image gotten by the bi-linear interpolation method);

finding a PSF(P) of a  $f=Pg$  function after finding the PSF (H) from the defined added function M(f); and

restoring the requested high resolution image f by finding an added filter coefficient Q of the PSF(P) and interpolation filter B from the equation  $f=Pg=PBz=Qz$ ;

wherein the PSF(H) is found by an equation

$$H(k, l) = \frac{G(k, l)}{F(k, l)},$$

wherein G(k,l) is the component in the k,l frequency region of the bi-linear interpolated image, and F(k,l) is the component in the k,l frequency region of the high resolution image.]

[11. A filtering control method for improving the image quality of a bi-linear interpolated image when recovering a high resolution image from a low resolution image, comprising:

defining an added function M(f) for finding a PSF(H) from an equation  $g=Bz=Hf+n$  (wherein B, H are bi-linear filters, n is a noise component generated by an assumed H when the H is a PSF (Point Spread Function), f is a requested high resolution image, z is a low resolution image, and g is a high resolution image gotten by the bi-linear interpolation method);

finding a PSF(P) of a  $f=Pg$  function after finding the PSF (H) from the defined added function M(f); and

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restoring the requested high resolution image  $f$  by finding an added filter coefficient  $Q$  of the PSF( $P$ ) and interpolation filter  $B$  from the equation  $f=Pg=PBZ=Qz$ ; wherein the PSF( $P$ ) is found by using an IFT (Inverse Fourier Transform) by an equation

$$P(k, l) = \frac{H^*(k, l)}{H^*(k, l)H(k, l) + C^*(k, l)C(k, l)}$$

]

**[12.** The filtering control method for improving the image quality of the bi-linear interpolated image according to claim **11**, wherein the number of a kernel of the PSF( $P$ ) is differently set in accordance with an up-sampling value of the image.]

13. A method for generating pixel data, the method performed by at least one processor and the method comprising: generating a set of interpolated pixel data from a set of original pixel data from an original image, wherein interpolated pixel data for a particular pixel is generated by performing operations comprising:

selecting original pixel data,

obtaining at least first and second filter coefficients, the first and second filter coefficients configured to interpolate the original pixel data, and the first filter coefficient comprising weighting factors having at least three at least three individual values;

applying the first filter coefficient to the selected original pixel data to produce first interpolated original pixel data, wherein applying the first filter coefficient to the selected original pixel data comprises:

multiplying each of the weighting factors and the selected original pixel data to produce weighted pixel data;

summing the weighted pixel data to produce the first interpolated pixel data; and

applying the second filter coefficient to the first interpolated original pixel data to produce second interpolated pixel data; and

generating the pixel data by performing a bit operation on the second interpolated pixel data.

14. The method of claim 13, wherein the second filter coefficient is a matrix including one or more individual numeric values.

15. The method of claim 14, wherein the first filter coefficient is a point spread function ( $P$ ) and the second filter coefficient is a bi-linear interpolation filter ( $B$ ).

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16. The method of claim 13, wherein: the first filter coefficient includes at least three different coefficient values, and generating the interpolated pixel data comprises dividing second interpolated pixel data by a sum of the at least three different coefficient values.

17. The method of claim 13, wherein the first filter coefficient and the second filter coefficient comprise at least one integer value.

18. The method of claim 13, wherein the first filter coefficient and the second filter coefficient are one.

19. The method of claim 13, wherein the second filter coefficient is one.

20. The method of claim 13, wherein the bit operation comprises a bit shift operation.

21. The method of claim 13, wherein the original image is obtained from a low-resolution imaging system.

22. The method of claim 13, wherein the original image is obtained from video data configured to represent motion.

23. A digital video system comprising:

a low-resolution imaging system configured to capture an original image; and

a processor configured to generate an interpolated image from the original image and to obtain interpolated pixel data for the interpolated image from original pixel data from the original image, wherein the interpolated pixel data for a particular pixel of the interpolated image is generated by performing operations comprising:

selecting original pixel data for the interpolated image, obtaining at least first and second filter coefficients, the first and second filter coefficients configured to interpolate the original pixel data, and the first filter coefficient comprising weighting factors having at least three at least three individual values,

applying the first filter coefficient to the selected original pixel data to produce first interpolated original pixel data, wherein applying the first filter coefficient to the selected original pixel data comprises:

multiplying each of the weighting factors and the selected original pixel data to produce weighted pixel data;

summing the weighted pixel data to produce the first interpolated pixel data;

applying the second filter coefficient to the first interpolated original pixel data to produce second interpolated pixel data, and

generating the interpolated image by performing a bit operation to the second interpolated pixel data.

\* \* \* \* \*

UNITED STATES PATENT AND TRADEMARK OFFICE  
**CERTIFICATE OF CORRECTION**

PATENT NO. : RE42,747 E  
APPLICATION NO. : 12/424927  
DATED : September 27, 2011  
INVENTOR(S) : Hodgins et al.

Page 1 of 1

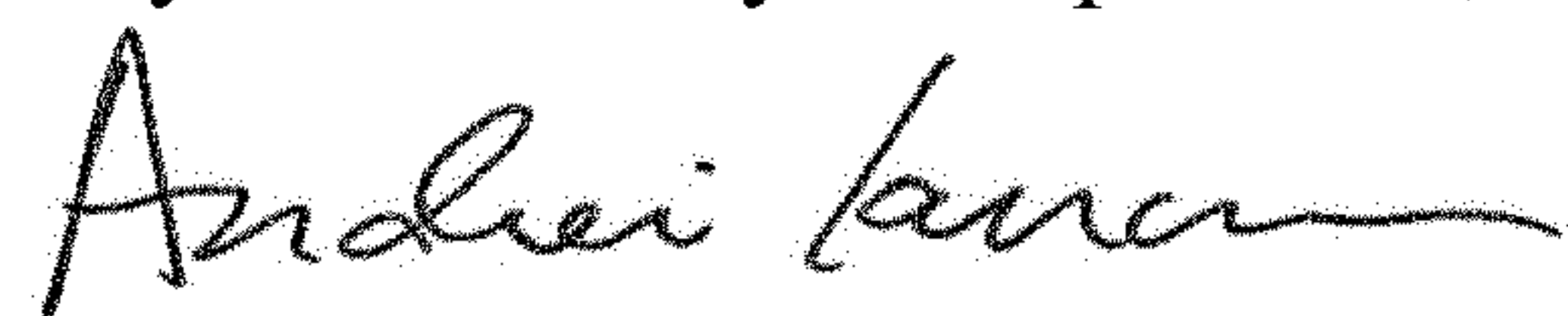
It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Specification

At Column 1, under the heading "CROSS-REFERENCE TO RELATED APPLICATIONS," replace Lines 14-23 (approx.) in their entirety and the portion of Line 24 (approx.) that includes "954" with the following:

*--NOTICE: More than one reissue application has been filed for the reissue of U.S. Patent No. 6,803,954 B1. The reissue applications are U.S. Reissue Patent Application Serial No. 12/424,927 (the present application), filed on April 16, 2009, now U.S. Reissue Patent No. RE42,747 E, issued September 27, 2011, and U.S. Reissue Patent Application Serial No. 12/024,408, filed on February 1, 2008, now abandoned, which are a continuation reissue application and a divisional reissue application, respectively, of U.S. Reissue Patent Application Serial No. 11/546,484, filed on October 12, 2006, now U.S. Reissue Patent No. RE42,045 E, issued January 18, 2011, which is a reissue application of U.S. Patent Application Serial No. 09/692,156, filed on October 20, 2000, now U.S. Patent No. 6,803,954 B1, issued October 12, 2004,--*

Signed and Sealed this  
Twenty-second Day of September, 2020



Andrei Iancu  
Director of the United States Patent and Trademark Office