

**A method and apparatus for processing a digital picture, a
picture encoding device and a picture decoding device**

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BACKGROUND OF THE INVENTION

The invention relates to a method and an apparatus for processing a digital picture, a picture encoding device and a picture decoding device.

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In block-based transform coding schemes, the most noticeable artefact after the decoding operation is the blocking artefact that is caused by independent block processing in a picture encoding device such as a picture encoding device encoding a picture according to a JPEG or an MPEG standard.

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Apart from blocking, a ringing artefact is another annoying artefact that often appears in a wavelet and subband based compression scheme such as the compression scheme according to the JPEG 2000 scheme.

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The coding artefacts lead to a noticeable deterioration in the subjective quality of the decoded picture that increases with increasing compression rate of the picture data.

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Various methods are known for reducing coding artefacts in the block-based transformation encoding using picture post-processing of a decoded digital picture, which are described in the articles [1], [2], for example.

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The work in post-processing for subband and wavelet coding was first reported in [3]. [3] discloses the decoding process as a maximum a posterior (MAP) estimation problem, which results in a convex optimization problem that is solved by gradient descent search iteratively.

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Another method employed projection onto convex sets (POCS) based scheme, which are typically more computationally complex because they are multi-pass in nature.

5 Furthermore, it is known from [4] and [5] to apply regularizations to the restoration of a digital picture in general and to the reduction of coding artefacts in particular (see [6]).

10 Further, [7] discloses the usage of a divide-and-conquer (DAC) strategy to solve the minimization problem. However, the approach according to [7] merely involves a quadratic function that usually yields an oversmooth solution.

15 However, there is still an emerging need for a post-processing of a digital picture which yield an improved quality by reducing artefacts.

20 SUMMARY OF THE INVENTION

Therefore, it is an object of the invention to reduce the artefacts in a digital picture.

25 The object is achieved with a method and an apparatus for processing a digital picture, a picture encoding device and a picture decoding device with the features according to the independent claims.

30 In a method for processing a digital picture comprising picture points, wherein coding information is assigned to the picture points, an iterative filtering for at least a part of the picture points of the picture using a regularization function is applied. In the filtering process, which
35 comprises an arbitrary number of iterations, in each iteration, the filtering is performed for two picture points respectively. The regularization function includes a term

that ensures the fidelity of the picture and a smoothness constraint.

5 An apparatus for processing a digital picture comprising picture points, wherein coding information is assigned to the picture points, comprises a processing unit which is adapted to perform the steps described above.

10 Furthermore, a picture encoding device for encoding a digital picture comprising picture points, wherein coding information is assigned to the picture points, comprises a picture encoding unit for encoding the digital picture and a picture decoding unit for decoding the encoded picture, for example in an encoding scheme for encoding
15 moving pictures, e.g. according to MPEG1, MPEG2, MPEG-4, H.263, H.263+ or H.263L.

Furthermore, the picture encoding device comprises a post-processing unit for post-processing the decoded picture, the
20 post-processing unit being adapted to perform the following steps:

- applying an iterative filtering for at least a part of the picture points of the picture using a regularization function,
- 25 • wherein in each iteration, the filtering is performed for two picture points respectively, and
- wherein the regularization function includes a term that ensures the fidelity of the picture and a smoothness constraint.

30 In this context it should be mentioned that the invention may be applied to the encoding and decoding of a still picture (e.g. according to JPEG, JPEG 2000) as well as to the encoding and decoding of a moving picture, in other words, in
35 video encoding and video decoding.

A picture decoding device for decoding an encoded digital picture comprising picture points, wherein coding information is assigned to the picture points, comprises

- 5 - a picture decoding unit for decoding the encoded picture,
- a post-processing unit for post-processing the decoded picture, the post-processing unit being adapted to perform the following steps:
 - 10 • applying an iterative filtering for at least a part of the picture points of the picture using a regularization function,
 - wherein in each iteration, the filtering is performed for two picture points respectively, and
 - 15 • wherein the regularization function includes a term that ensures the fidelity of the picture and a smoothness constraint.

The invention may be seen in that the post-processing is formulated as a picture restoration and estimation problem, which leads to a constrained optimization problem. The constraints are expressed through a regularization function, which is also called the potential function in Markov random field approach. In order to preserve edges and remove the ringing artefacts a non-quadratic potential function is preferably used.

According to a preferred embodiment of the invention, the regularization function is a half-quadratic regularization function.

According to a further preferred embodiment of the invention, the regularization function includes an edge-preserving constraint.

Preferably, the regularization function is

$$\Phi(\underline{x}, \underline{y}) = \Phi_1(\underline{x}, \underline{y}) + \lambda \Phi_r(\underline{x})$$

with

$\Phi_1(\underline{x}, \underline{y})$ being the term that ensures the fidelity of the
5 picture, and

$$\Phi_r(\underline{x}) = \sum_{p=1}^P \sum_{(i,j) \in S} \phi(D_{i,j}^{(p)} \underline{x})$$

including the smoothness constraint,

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wherein

- $\underline{y}$ is the coding information of a given picture array
with a predetermined number of picture points,
- $\underline{x}$ is the estimated coding information of the picture
15 without noise,
- λ is a weighting factor,
- $D_{i,j}^{(p)}$ is a p-order difference operator,
- ϕ is a potential real function having edge-preserving
properties,
- 20 • i is a first index for denoting a place in the picture
array in a first direction,
- j is a second index for denoting a place in the picture
array in a second direction, which second direction is
different from the first direction,
- 25 • S is the amount of all picture points in the picture
array.

The term that ensures the fidelity of the picture $\Phi_1(\underline{x}, \underline{y})$ may
be

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$$\Phi_1(\underline{x}, \underline{y}) = \|\underline{y} - \underline{x}\|^2.$$

According to a further embodiment of the invention, a
difference operator having a order of one is used.

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The regularization function preferably comprises an auxiliary variable $\underline{b}$ such that the regularization function is an infimum function according to the following formula

$$5 \quad \Phi(\underline{x}, \underline{y}) = \inf_{\underline{b}} \Phi^*(\underline{x}, \underline{y}, \underline{b}),$$

with $\Phi^*(\underline{x}, \underline{y}, \underline{b})$ being a quadratic function in $\underline{x}$ when the auxiliary variable $\underline{b}$ is fixed.

10 The quadratic function $\Phi^*(\underline{x}, \underline{y}, \underline{b})$ may result from

$$\Phi^*(\underline{x}, \underline{y}, \underline{b}) = \|\underline{y} - \underline{x}\|^2 + \lambda \sum_p \sum_{(i,j) \in S} \left\{ b_{i,j} \left(D_{i,j}^{(p)} \underline{x} \right)^2 + \psi[b_{i,j}] \right\}$$

wherein

- 15 • $b_{i,j}$ is an auxiliary variable for the picture point at the place (i,j) in the picture array,
- $\psi[b_{i,j}]$ is a strictly convex and decreasing function.

20 According to a further embodiment of the invention, the auxiliary variables $b_{i,j}$ and the estimated coding information $\underline{x}$ are optimised in each iteration alternately, wherein

- in the case that the auxiliary variables $b_{i,j}$ are optimized, the estimated coding information $\underline{x}$ is fixed, and
- 25 • in the case that the estimated coding information $\underline{x}$ is optimized, the auxiliary variables $b_{i,j}$ are fixed.

According to a further embodiment of the invention, the quadratic function $\Phi^*(\underline{x}, \underline{y}, \underline{b})$ is solved using a divide and

30 conquer process for decomposing and recomposing the quadratic function $\Phi^*(\underline{x}, \underline{y}, \underline{b})$.

According to a further embodiment of the invention, the estimated coding information $x_{i,j}$ at the place (i,j) in the picture array and $x_{i,j+1}$ at the place $(i,j+1)$ in the picture array is determined using the following formulas:

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$$x_{i,j} = y_{i,j} - \sigma_{i,j}(y_{i,j} - y_{i,j+1}),$$

$$x_{i,j+1} = y_{i,j+1} + \sigma_{i,j}(y_{i,j} - y_{i,j+1}),$$

10 wherein

$$\sigma_{i,j} = \frac{\lambda b_{i,j}}{1 + 2\lambda b_{i,j}} \quad i = 0, \dots, M-1; j = 0, \dots, N-1.$$

15 According to a further embodiment of the invention, the first direction and the second direction are perpendicular to each other.

20 According to a further embodiment of the invention, a third direction being angled to the first direction with an angle of 45° and a fourth direction being angled to the second direction with an angle of 45° are taken into account.

25 According to a further embodiment of the invention, a third direction first order difference operator $D_{i,j}^{d+} \underline{x}$ and a fourth direction first order difference operator $D_{i,j}^{d-} \underline{x}$ are used,

wherein

- the third direction first order difference operator $D_{i,j}^{d+} \underline{x}$ is determined according to the following formula:

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$$D_{i,j}^{d+} \underline{x} = \frac{(x_{i,j} - x_{i+1,j+1})}{\sqrt{2}}, \text{ and}$$

- the fourth direction first order difference operator $D_{i,j}^{d-}x$ is determined according to the following formula:

$$D_{i,j}^{d-}x = \frac{(x_{i,j} - x_{i+1,j-1})}{\sqrt{2}}.$$

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According to a further embodiment of the invention, the picture is encoded using a wavelet transformation.

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BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a flow chart of the post-processing on the decompressed picture according to the preferred embodiment of the invention;

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Figure 2 shows a flow chart of the line processing along a horizontal direction according to the preferred embodiment of the invention;

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Figure 3 shows a block diagram illustrating a video encoder according to a preferred embodiment of the invention;

Figure 4 shows the block diagram of the pixel-based

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processing unit according to a preferred embodiment of the invention.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT OF THE INVENTION

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A preferred embodiment of the invention will now be described with reference to the accompanying drawings.

35 **Fig.3** shows a video encoder 300 for encoding a digital video sequence 301.

The digital video sequence 301 is a sequence of subsequent digital pictures 302 (digital frames) comprising picture elements.

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The picture elements of each picture 302 are grouped in picture blocks, each picture block comprising 8×8 picture elements or 16×16 picture elements.

10 In this context it should be pointed out that the invention is not restricted to a specific form of picture blocks, the picture elements are grouped in, in particular, the invention is not restricted to a specific number of picture elements in a picture block.

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Any form of picture block with any number of picture elements may be used in the motion estimation according to the invention.

20 Four picture blocks with luminance information and two picture blocks with chrominance information are grouped into one macroblock, respectively.

According to this preferred embodiment of the invention, each
25 picture 302 comprises 16×16 macroblocks.

Luminance information and chrominance information is assigned to one picture element or to a plurality of picture element (in the case of sub-sampling) as coding information.

30

In a selecting unit 303, each picture 302 is selected and it is determined whether it is to be coded in a so called INTER-mode or the so called INTRA-mode.

35 If the selected picture is to be coded in the INTER-mode, i.e. in a differential mode, for each macroblock in the current picture to be coded (denoted as first picture), a

motion estimation is provided in a motion estimation unit 304 with reference to a reference picture. The reference picture may be a preceding picture or a following picture of the first picture in the video sequence 301.

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As a result of the motion estimation, a motion vector describing the displacement of the macroblock in the current picture compared with the selected best matched macroblock in the reference picture, is determined.

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The coding mode 305 for the selected picture 301 and the determined motion vectors 306 are provided to and stored in a picture storage element 307.

15 The motion estimation will further be described in detail.

In the INTER-coding mode, the data 308 in the macroblocks (the coding information) is provided to a subtracting unit 309, where the data 310 of the macroblock from the reference picture, which macroblock has been matched and selected according to the motion estimation is subtracted, thereby generating motion estimation error coefficients 311.

20

In the INTRA-coding mode, no subtraction and no motion estimation is provided. In the INTRA-coding mode, the entire luminance information and the entire chrominance information of the selected picture to be coded is coded, not only a differential signal as in the INTER-coding mode. In the INTRA-coding mode, INTRA-coefficients 311 are output by the subtracting unit 309.

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The motion estimation error coefficients 311 or the INTRA coefficients 311 are provided to a transformation unit 312.

35 In the transformation unit 312, a discrete cosine transformation (DCT) is provided to the input motion estimation error coefficients 311 or the INTRA coefficients

311, thereby generating transformation coefficients 313, which are provided to a quantizing unit 314.

Alternatively, any suitable type of transformation for
5 generating the transformation coefficients 313 can be used according to the invention, e.g. the wavelet transformation.

In the quantizing unit 314, the transformation coefficients 313 are quantized and scanned, thereby generating quantized
10 transformation coefficients 315, which are provided to a entropy coding unit 316 and to an inverse quantizing unit 318.

In the entropy coding unit 316, a variable length encoding,
15 such as a Lempel-Ziv-Encoding or a Huffman encoding is performed on the quantized transformation coefficients 315. Furthermore, a run length encoding algorithm is performed on the variable length encoded quantized transformation coefficients.

20 The resulting coded data stream 317 is output by the video encoder 300 and, for example, transmitted to a video decoder unit.

25 Furthermore, in the inverse quantizing unit 318, the quantized transformation coefficients 315 are inversely quantized, thereby generating inverse quantized transformation coefficients 319, which are provided to an inverse transformation unit 320.

30 In the inverse transformation unit 320, an inverse discrete cosine transformation (IDCT), generally the respective inverse transformation to the transformation used for generating the transformation coefficients, e.g. the inverse
35 wavelet transformation, is performed on the inverse quantized transformation coefficients 319, thereby generating inverse

transformed coefficients 321, which are provided to a first input 322 of an adder 323.

The data 310 of the macroblock from the reference picture, which macroblock has been matched and selected according to the provided motion estimation is provided to a second input 324 of the adder 323, thus being added to the inverse transformed coefficients 321 in the INTER-mode, thereby generating a reconstructed signal 325.

The reconstructed signal 325 output by the adder 323 is stored in the picture storage element 307.

The thus reconstructed picture stored in the picture storage element 307 is further provided to a post-processing unit 326 as a picture signal 327.

The post-processing unit 326 performs a post-processing on the picture signal 327 as will be later described in detail.

The resulting post-processed picture signal 328 is provided to and stored in the picture storage element 307 as a post-processed picture 329.

Now, a motion estimation will be performed on the respective post-processed picture 329.

It should be noted that the invention is not restricted to the architecture of the above-described encoder 300.

The invention may be applied to any other encoding architecture and decoding architecture, for example in an object-oriented encoding scheme like MPEG4 or in a hybrid block-based encoding scheme and object-oriented encoding scheme, a still picture encoding scheme and decoding scheme such as the JPEG scheme or the JPEG 2000 scheme.

It should be noted that the described post-processing can be applied to the decoded pictures without altering the coder and/or decoder scheme and requiring any aside information.

- 5 One aspect of the invention may be seen in that an edge-preserving and smoothness constraint is imposed on the picture points while retaining fidelity to the picture.

The constraints are expressed through a regularization
10 function, which is also called potential function in the Markov random field approach. A simple and common used potential function is quadratic, however, it yields oversmooth solutions. In order to preserve edges and remove the ringing artefacts a non-quadratic potential function is
15 used, which results in a constrained optimization problem.

Using an auxiliary variable in the regularization function, as later will be described in detail, permits us to linearize the problem and to derive a deterministic method based on
20 alternative minimizations on the picture variable and the auxiliary variable.

However, the minimization on the picture variable is still a calculation intensive task. For solving this problem, a
25 divide-and-conquer (DAC) strategy to improve the calculation speed is applied.

The basic idea of the DAC strategy is to divide a large problem into pieces, to solve the divided sub-problems
30 separately and then to combine the sub-solutions into a full solution.

Based on the half-quadratic regularization and the DAC strategy, a simple and therefore effective and less
35 calculation consuming post-processing method for removing artefacts in the decoded picture is provided.

Experimental results have shown that the proposed method significantly suppresses especially ringing artefacts and improve both objective and subjective quality of a decoded picture.

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According to this preferred embodiment of the invention, a picture is regarded as a degraded version from a blurred and noisy observation.

10 The artefact reduction problem is considered as an estimation problem, i.e. to estimate or recover a 2-D signal from a noisy signal, which can be represented as follows:

$$\underline{y} = \underline{x} + \underline{\xi}, \quad (1)$$

15

wherein $\underline{y}$ is a given picture array and $\underline{\xi}$ is a mixture of outliers and the nominal noise distribution.

20 The goal of artefact reduction is to estimate the "ideal" picture, further denoted as the picture to be estimated $\underline{x}$, from the given picture array $\underline{y}$.

According to this preferred embodiment of the invention, the pictures are considered as lexicographically ordered vectors.

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If $\underline{\xi}$ is a white Gaussian noise, the restored picture is the maximum a posteriori (MAP) estimation. In general case, the distribution of $\underline{\xi}$ is unknown.

30 According to a priori information about the true picture, the solution is to minimize a cost function $\Phi(\underline{x}, \underline{y})$, which can be written as following

$$\hat{\underline{x}} = \arg \min_{\underline{x}} \Phi(\underline{x}, \underline{y}), \quad (2)$$

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$$\Phi(\underline{x}, \underline{y}) = \Phi_1(\underline{x}, \underline{y}) + \lambda \cdot \Phi_r(\underline{x}) \quad (3)$$

$$\Phi_1(\underline{x}, \underline{y}) = \|\underline{y} - \underline{x}\|^2, \quad (4)$$

where $\Phi_r(\underline{x})$ is a roughness penalty regularization, which is expressed as the following formula:

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$$\Phi_r(\underline{x}) = \sum_{p=1}^P \sum_{(i,j) \in S} \phi(D_{i,j}^{(p)} \underline{x}), \quad (5)$$

wherein ϕ is a real function, and each $D^{(p)}$ is a p-order difference operator,

10

$$\underline{x} = \{x_{i,j}, (i,j) \in S\}$$

$$S = \{(i,j) : i \in [0, M-1], j \in [0, N-1]\}.$$

15 In the formula (3), the second term $\Phi_r(\underline{x})$ imposes a smoothness constraints or roughness penalty. The first term $\Phi_1(\underline{x}, \underline{y})$ ensures fidelity to the picture. λ is a positive parameter that balances these two terms.

20 For removing coding artefact the picture points are processed with an edge preservation.

According to this embodiment of the invention, a simple and thus very effective model is used, namely first order
25 derivatives.

For example, at site (i,j) , the first order horizontal difference $(D_h y)_{i,j}$ and the first order vertical difference $(D_v y)_{i,j}$ from the decompressed picture $\underline{y}$ is calculated
30 according to the following formulas:

$$(D_h y)_{i,j} = y_{i,j} - y_{i,j+1}$$

$$(D_v y)_{i,j} = y_{i,j} - y_{i+1,j}. \quad (6)$$

ϕ in formula (5) is known as the potential function. This potential function assigns a cost to every value of the picture gradient, and thus has some edge-preserving properties.

It is assumed that Φ has a minimum in $\underline{x}$, which assumption results in:

$$\frac{1}{2} \Phi'(\underline{x}, \underline{y}) = 0, \quad (7)$$

wherein $\Phi'(\underline{x}, \underline{y})$ is the derivative of $\Phi(\underline{x}, \underline{y})$.

Equation (7) can be written as

$$\underline{x} - \underline{y} - \lambda \cdot \underline{\Gamma} \cdot \underline{x} = 0, \quad (8)$$

wherein $\underline{\Gamma}$ is a matrix that represents a weighted discrete approximation of the Laplacian operator.

The weights of the Laplacian operator are given by the function $\frac{1}{2t} \cdot \frac{\partial \phi(t)}{\partial t}$.

There are two cases to be considered.

First, for a homogeneous area of the picture, i.e. all gradients around the site (i, j) are close to zero. All weights are approximately equal to the same value.

Second, for a discontinuity case in the neighborhood of the site (i, j) , the corresponding weights vanish and thus the edge is preserved. Also, it seems natural that there should be a one-to-one correspondence between values of the gradient and values of the weight. This requires that the weighting function must be strictly monotonous on $[0, +\infty)$.

There are many functions that satisfy those conditions. In this preferred embodiment of the invention, the following function is chosen as the potential function.

$$\phi(t) = \log(1 + t^2). \quad (9)$$

According to this preferred embodiment of the invention implicitly the following assumption is made, that is, a large value of the gradient corresponds to an edge which should be preserved while a small value of the gradient should be smoothed which is correspondent to an artefact.

Since the conditions according to formula (8) are nonlinear, it is time consuming to minimize the MAP criterion even in the convex case.

Therefore, an auxiliary variable $\underline{b}$ is introduced to make the solution easier. The MAP criterion can be written as the minimum of a dual energy

$$\Phi(\underline{x}, \underline{y}) = \inf_{\underline{b}} \Phi^*(\underline{x}, \underline{y}, \underline{b}). \quad (10)$$

$\Phi^*(\underline{x}, \underline{y}, \underline{b})$ is a quadratic function when the auxiliary variable $\underline{b}$ is fixed.

$$\Phi^*(\underline{x}, \underline{y}, \underline{b}) = \|\underline{y} - \underline{x}\|^2 + \lambda \sum_p \sum_{(i,j) \in S} \left\{ b_{i,j} \left(D_{i,j}^{(p)} x \right)^2 + \psi[b_{i,j}] \right\}, \quad (11)$$

wherein $\psi[b_{i,j}]$ is a strictly convex and decreasing function.

When the auxiliary variable $\underline{b}$ is fixed, the augmented energy becomes quadratic in $\underline{x}$. Also, $\Phi^*(\underline{x}, \underline{y}, \underline{b})$ is convex in the auxiliary variable $\underline{b}$ when $\underline{x}$ is fixed.

According to the theorem 1 described in [5], the minimum value of the auxiliary variable $\underline{b}$ is unique and is given by the following formula:

$$5 \quad b_{i,j} = \frac{1}{2(p_{i,j}x)} \frac{\partial \phi(p_{i,j}x)}{\partial (p_{i,j}x)}. \quad (12)$$

In the following, the recovery method will be described in detail.

- 10 Using a half-quadratic regularization, it should be noted that minimizing the MAP energy is equivalent to minimizing the augmented energy with the auxiliary variable $\underline{b}$.

Therefore, the minimization of the dual energy can be carried
15 on alternate minimizations over $\underline{x}$ and the auxiliary variable $\underline{b}$, which is given as follows:

Begin

Initialization: $\underline{x}^0 = \underline{0}$

20 Do {

$$\underline{b}^{n+1} = \arg \min_{\underline{b}} \{ \Phi^*(\underline{x}^n, \underline{b}) \}$$

$$\underline{x}^{n+1} = \arg \min_{\underline{x}} \{ \Phi^*(\underline{x}^n, \underline{b}^{n+1}) \}$$
 } Until convergence

End

25

At step $n+1$, $\underline{x}^n$ is fixed, $\underline{b}^{n+1}$ is computed using equation (12).

The minimization over $\underline{x}$ becomes a simpler problem since
30 $\Phi^*(\underline{x}^n, \underline{b}^{n+1})$ is quadratic.

In the following, a divide and conquer strategy is applied to solve this equation.

It is assumed that the constraints in equation (3) are decomposed into a summation of subterms in an interleaved fashion such that each subterm accounts for a part of the total directional variation.

5

The following function is used:

$$\Phi^*(\underline{x}, \underline{y}) = \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} (y_{i,j} - x_{i,j})^2 + \lambda \cdot \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} [b_{i,j} (D_{i,j}^x)^2 + \psi(b_{i,j})]. \quad (13)$$

10 Taking the partial derivations $\frac{\partial \Phi^*(\underline{x}, \underline{y})}{\partial x_{i,j}}$ and setting them to zero yields the following equations.

$$x_{i,j} - y_{i,j} + \lambda \cdot b_{i,j} \cdot (x_{i,j} - x_{i,j+1}) = 0,$$

$$15 \quad x_{i,j+1} - y_{i,j+1} - \lambda \cdot b_{i,j} \cdot (x_{i,j} - x_{i,j+1}) = 0. \quad (14)$$

Solving the equations (14) yields the following solutions

$$x_{i,j} = y_{i,j} - \sigma_{i,j} (y_{i,j} - y_{i,j+1})$$

20

$$x_{i,j+1} = y_{i,j+1} + \sigma_{i,j} (y_{i,j} - y_{i,j+1}), \quad (15)$$

where

$$25 \quad \sigma_{i,j} = \frac{\lambda \cdot b_{i,j}}{1 + 2\lambda \cdot b_{i,j}} \quad i = 0, \dots, M-1; j = 0, \dots, N-1. \quad (16)$$

The complete post-processing includes a line process along +45° and -45° directions, i.e. diagonal directions.

30 The difference functions in this case are written as

$$D_{i,j}^{d+x} = \frac{(x_{i,j} - x_{i+1,j+1})}{\sqrt{2}}$$

$$D_{i,j}^{d-x} = \frac{(x_{i,j} - x_{i+1,j-1})}{\sqrt{2}} \quad (17)$$

5 **Fig.1** shows the separate steps for the post-processing on the decompressed picture in summary.

The picture data is input into the post-processing unit 326.

10 In a first stage (block 100), a first post-processing is performed along the horizontal direction of the picture array. Then, in a second stage (block 200), a second post-processing is performed along the horizontal direction of the picture array. Subsequently, in a third stage (block 300), a
15 third post-processing is performed again along the +45° direction of the picture array and in a fourth and last stage (block 400), a fourth post-processing is performed along the -45° direction of the picture array.

20 Afterwards, the post-processed picture data is output by the post-processing unit 326.

Fig.2 shows an example of the post-processing along the horizontal direction of the picture array.

25 In a first step (step 101), the indices i, j for denoting the line and the column of the picture array are initialised to a value "0", respectively.

30 In a second step (step 102), two adjacent image picture points are input sequentially for post-processing into the post-processing unit 326.

35 In a further step (step 103), a pixel-based processing, in other words, a pixel-based filtering is performed. This means that the coding information that is assigned to the

respective picture points is adapted according to the formula (15) described above.

In a further step (step 104) it is determined whether

5

$$j = M - 2.$$

In other words, it is determined whether all picture points of the current row have been processed.

10

If there are still some picture points of the current row to be filtered, the column index j is increased by 2 (step 105), i.e.

15
$$j = j + 2.$$

In other words, the post-processing is performed for the next two consecutive picture points of the current row i .

20 If $j = M - 2$, the picture points of the same row (row index i remains unchanged) are re-process with an initial index shift of $j = 1$ (step 106).

This means, that the pixel-based processing (step 103) is
25 again performed with an altered initial column index j .

In a further step (step 107), it is determined whether

$$j = M - 3.$$

30

In other words, it is determined whether all picture points of the current row have been processed with the altered initial column index $j = 1$.

35 If there are still some picture points of the current row to be filtered, the column index j is increased by 2 (step 108),

i.e. $j = j + 2$ and the next two picture points of the current row i are input (step 109).

In other words, the post-processing is performed for the next
5 two consecutive picture points of the current row i .

If $j = M - 3$, it is further determined (step 110) whether the iteration has been finished.

10 If the iteration has not been finished, the loop is repeated using the unchanged row index i and the column index is reset to the value "0" ($i = i; j = 0$) (step 111).

If the iteration has been finished, it is further determined
15 in a further step (step 112) whether the row index has the value $i = N - 1$. In other words, it is determined whether the current row is the last row of the picture array taken into account.

20 If the row index does not have the value $i = N - 1$, the loop is repeated for the next row, i.e. the row index i is increased and the column index is reset to the value "0" ($i = i + 1; j = 0$) (step 113).

25 If the row index has the value $i = N - 1$, the method goes on to the second stage (stage 200). The second stage (stage 200), the third stage (stage 300) and the fourth stage (stage 400) include the same steps compared to the first stage (stage 100). However, in the second stage (stage 200) and in
30 the fourth stage (stage 400), the row index and the column index is exchanged in the respective steps, i.e. for example, that the row index i is increased by 2 in the respective steps and the post-processing is performed column by column instead of the post-processing row by row according to the
35 first stage (stage 100).

Fig. 4 shows the filtering step 103 in more detail. The filtering step is an implementation of formula (15) described above.

- 5 Two adjacent picture points (with coding information $y_{i,j}$, $y_{i,j+1}$) are read from the picture storage medium 307 (step 401).

For the two adjacent picture points 402, to be more exact,
10 for the coding information of the two adjacent picture points ($y_{i,j}$, $y_{i,j+1}$), a first difference ($y_{i,j+1} - y_{i,j}$) is calculated. The first difference ($y_{i,j+1} - y_{i,j}$) is multiplied by the weighting coefficient $\sigma_{i,j}$ 403 resulting in the term $[\sigma_{i,j}(y_{i,j+1} - y_{i,j})]$.

15 In order to calculate the estimated value $x_{i,j}$ 404 of the coding information for the picture point at the site (i,j), the term $[\sigma_{i,j}(y_{i,j+1} - y_{i,j})]$ is added to the coding information $y_{i,j}$.

20 In order to calculate the estimated value $x_{i,j+1}$ 405 of the coding information for the picture point at the site (i,j+1), the term $[\sigma_{i,j}(y_{i,j+1} - y_{i,j})]$ is subtracted from the coding information $y_{i,j+1}$.

25 In a last step (step 406), the post-process picture points are stored in the picture storage medium 307.

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CLAIMS

What is claimed is:

5 1. A method for processing a digital picture comprising picture points, wherein coding information is assigned to the picture points, comprising the following steps:

- applying an iterative filtering for at least a part of the picture points of the picture using a regularization function,
- 10 • wherein in each iteration, the filtering is performed for two picture points respectively, and
- wherein the regularization function includes a term that ensures the fidelity of the picture and a smoothness
- 15 constraint.

2. The method according to claim 1, wherein the regularization function is a half-quadratic regularization function.

20

3. The method according to claim 1 or 2, wherein the regularization function includes an edge-preserving constraint.

25 4. The method according to any of the claims 1 to 3, wherein the regularization function is

$$\Phi(\underline{x}, \underline{y}) = \Phi_1(\underline{x}, \underline{y}) + \lambda \Phi_r(\underline{x})$$

30 with

$\Phi_1(\underline{x}, \underline{y})$ being the term that ensures the fidelity of the picture, and

$$35 \quad \Phi_r(\underline{x}) = \sum_{p=1}^P \sum_{(i,j) \in S} \phi\left(D_{i,j}^{(p)} \underline{x}\right)$$

including the smoothness constraint,

wherein

- y is the coding information of a given picture array with a predetermined number of picture points,
- x is the estimated coding information of the picture without noise,
- λ is a weighting factor,
- $D_{i,j}^{(p)}$ is a p -order difference operator,
- ϕ is a potential real function having edge-preserving properties,
- i is a first index for denoting a place in the picture array in a first direction,
- j is a second index for denoting a place in the picture array in a second direction, which second direction is different from the first direction,
- S is the amount of all picture points in the picture array.

5. The method according to claim 4, wherein the term that ensures the fidelity of the picture $\Phi_1(\underline{x}, \underline{y})$ is

$$\Phi_1(\underline{x}, \underline{y}) = \|\underline{y} - \underline{x}\|^2.$$

6. The method according to claim 4 or 5, wherein the difference operator having a order of one is used.

7. The method according to claim 4 or 5, wherein the regularization function comprises an auxiliary variable b such that the regularization function is an infimum function which results from

$$\Phi(\underline{x}, \underline{y}) = \inf_{\underline{b}} \Phi^*(\underline{x}, \underline{y}, \underline{b}),$$

with $\Phi^*(\underline{x}, \underline{y}, \underline{b})$ being a quadratic function in $\underline{x}$ when the auxiliary variable $\underline{b}$ is fixed.

- 5 8. The method according to claim 7,
wherein the quadratic function $\Phi^*(\underline{x}, \underline{y}, \underline{b})$ results from

$$\Phi^*(\underline{x}, \underline{y}, \underline{b}) = \|\underline{y} - \underline{x}\|^2 + \lambda \sum_p \sum_{(i,j) \in S} \left\{ b_{i,j} \left(D_{i,j}^{(p)} \underline{x} \right)^2 + \psi[b_{i,j}] \right\}$$

10 wherein

- $b_{i,j}$ is an auxiliary variable for the picture point at the place (i,j) in the picture array,
- $\psi[b_{i,j}]$ is a strictly convex and decreasing function.

- 15 9. The method according to claim 7 or 8,
wherein the auxiliary variables $b_{i,j}$ and the estimated coding information $\underline{x}$ are optimised in each iteration alternately,
wherein

- in the case that the auxiliary variables $b_{i,j}$ are
20 optimized, the estimated coding information $\underline{x}$ is fixed,
and
- in the case that the estimated coding information $\underline{x}$ is optimized, the auxiliary variables $b_{i,j}$ are fixed.

- 25 10. The method according to any of the claims 7 to 9,
wherein the quadratic function $\Phi^*(\underline{x}, \underline{y}, \underline{b})$ is solved using a divide and conquer process for decomposing and recomposing the quadratic function $\Phi^*(\underline{x}, \underline{y}, \underline{b})$.

- 30 11. The method according to any of the claims 7 to 10,
wherein the estimated coding information $x_{i,j}$ at the place (i,j) in the picture array and $x_{i,j+1}$ at the place $(i,j+1)$ in the picture array is determined using the following formulas:

$$x_{i,j} = y_{i,j} - \sigma_{i,j}(y_{i,j} - y_{i,j+1}),$$

$$x_{i,j+1} = y_{i,j+1} + \sigma_{i,j}(y_{i,j} - y_{i,j+1}),$$

5 wherein

$$\sigma_{i,j} = \frac{\lambda b_{i,j}}{1 + 2\lambda b_{i,j}} \quad i = 0, \dots, M-1; j = 0, \dots, N-1.$$

12. The method according to any of the claims 1 to 11,
10 wherein the first direction and the second direction are perpendicular to each other.

13. The method according to claim 12,
wherein a third direction being angled to the first direction
15 with an angle of 45° and a fourth direction being angled to the second direction with an angle of 45° are taken into account.

14. The method according to claim 13,
20 wherein a third direction first order difference operator $D_{i,j}^{d+} \underline{x}$ and a fourth direction first order difference operator $D_{i,j}^{d-} \underline{x}$ are used, wherein

• the third direction first order difference operator
25 $D_{i,j}^{d+} \underline{x}$ is determined according to the following formula:

$$D_{i,j}^{d+} \underline{x} = \frac{(x_{i,j} - x_{i+1,j+1})}{\sqrt{2}}, \text{ and}$$

• the fourth direction first order difference operator
30 $D_{i,j}^{d-} \underline{x}$ is determined according to the following formula:

$$D_{i,j}^{d-} \underline{x} = \frac{(x_{i,j} - x_{i+1,j-1})}{\sqrt{2}}.$$

15. The method according to any of the claims 1 to 14, wherein the picture is encoded using a wavelet transformation.

5 16. An apparatus for processing a digital picture comprising picture points, wherein coding information is assigned to the picture points, comprising a processing unit being adapted to perform the following steps:

- 10 • applying an iterative filtering for at least a part of the picture points of the picture using a regularization function,
- wherein in each iteration, the filtering is performed for two picture points respectively, and
- 15 • wherein the regularization function includes a term that ensures the fidelity of the picture and a smoothness constraint.

17. A picture encoding device for encoding a digital picture comprising picture points, wherein coding information is
20 assigned to the picture points, comprising

- a picture encoding unit for encoding the digital picture,
- a picture decoding unit for decoding the encoded picture,
- a post-processing unit for post-processing the decoded
25 picture, the post-processing unit being adapted to perform the following steps:
- applying an iterative filtering for at least a part of the picture points of the picture using a regularization function,
- 30 • wherein in each iteration, the filtering is performed for two picture points respectively, and
- wherein the regularization function includes a term that ensures the fidelity of the picture and a smoothness constraint.

18. A picture decoding device for decoding an encoded digital picture comprising picture points, wherein coding information is assigned to the picture points, comprising

- 5 - a picture decoding unit for decoding the encoded picture,
 - a post-processing unit for post-processing the decoded picture, the post-processing unit being adapted to perform the following steps:

- 10 • applying an iterative filtering for at least a part of the picture points of the picture using a regularization function,
 • wherein in each iteration, the filtering is performed for two picture points respectively, and
 • wherein the regularization function includes a term that
15 ensures the fidelity of the picture and a smoothness constraint.