Identification and Restoration of Degraded Image using Fast 2-D Block Kalman Filter with Colored Driving Source

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***Abstract*—We propose a fast image restoration method using the two-dimensional (2-D) block Kalman filter with colored driving source. The remarkable feature of proposed method is fast image restoration for degraded image including blur and additive noise without sacrificing the quality of the original image.**

I. Introduction

In [1], we have already proposed a robust image restoration method using only the 2-D block Kalman filter by modifying the canonical state space models: (i) a state equation is composed of the original image, and (ii) an observation equation is composed of the original image, blur, and additive noise, while the image restoration method based on the 2-D block Kalman filter [2],[3] are well known as effective image restoration approach consists of two stages in (1) auto-regressive (AR) parameter estimation and (2) image estimation using the Kalman filter algorithm. However, since this algorithm requires the calculation of inverse matrix, the conventional method requires high computational complexity by increasing the vector/matrix size.

In this paper, to overcome its drawback, we present a fast image restoration method with reduced computational complexity by recomposition the state space models of the 2-D block Kalman filter with colored driving source that authors proposed [1].

II. Proposed Method

Assuming that the original image $x_{i,j}$ is degraded by point spread function (PSF) $h_{i,j}$ and additive white Gaussian noise $v_{i,j}$, the observation image (degraded image) $y_{i,j}$ is given as [2]:

$$y_{i,j} = \sum_p \sum_q h_{i-p,j-q} x_{p,q} + v_{i,j} \quad (1)$$

The purpose of this paper is to achieve fast image restoration using only the observation image including blur and additive noise.

Fig.1 shows the spatial positions of $\boldsymbol{x}(n)$ at a given iteration "n", and illustrates the state propagation along the horizontal direction with $\boldsymbol{x}(n)$ and $\boldsymbol{x}(n+1)$. For the convenience of presentation as shown in Fig.1, define $L_i \times L_j = 6 \times 6$, $l \times m = 2 \times 2$, and $\boldsymbol{x}_{i,j}(n) = [x_{i,j}(n), x_{i+1,j}(n), x_{i,j+1}(n), x_{i+1,j+1}(n)]^T_{(i,j=1,2,3)}$, define the 36×1 state vector $\boldsymbol{x}(n) = [\boldsymbol{x}^T_{1,1}(n), \boldsymbol{x}^T_{2,1}(n), \cdots, \boldsymbol{x}^T_{3,3}(n)]^T$. We give state equation from only the original image $\{x_{i,j}\}$:

$$[\text{state equation}] \qquad \boldsymbol{x}(n+1) = \Phi \boldsymbol{x}(n) + \boldsymbol{\delta}(n+1) \quad (2)$$

where the 36×36 transition matrix Φ is upper shift matrix [1], and the 36×1 colored driving source vector $\boldsymbol{\delta}(n+1) = [0, \cdots, 0, \boldsymbol{x}^T_{1,4}(n+1), \boldsymbol{x}^T_{2,4}(n+1), \boldsymbol{x}^T_{3,4}(n+1)]^T$.

Furthermore, we define the 16×1 observation vector $\boldsymbol{y}(n) = [\boldsymbol{y}^T_{2,2}(n), \boldsymbol{y}^T_{1,3}(n), \boldsymbol{y}^T_{2,3}(n), \boldsymbol{y}^T_{3,3}(n)]^T$, we give observation equation using Eq.(1):

$$[\text{observation equation}] \qquad \boldsymbol{y}(n) = M\boldsymbol{x}(n) + \boldsymbol{\epsilon}(n) \quad (3)$$

where the 16×36 observation matrix M with PSF, and the 16×1 observation noise vector $\boldsymbol{\epsilon}(n) = [\boldsymbol{v}^T_{2,2}(n), \boldsymbol{v}^T_{1,3}(n), \boldsymbol{v}^T_{2,3}(n), \boldsymbol{v}^T_{3,3}(n)]^T$.

The proposed method restores original image from only the degraded image $\boldsymbol{y}^T_{2,2}(n)$,$\boldsymbol{y}^T_{1,3}(n)$,$\boldsymbol{y}^T_{2,3}(n)$, and $\boldsymbol{y}^T_{3,3}(n)$ using the 2-D block Kalman filter with colored driving source.

III. Numerical Simulation

We adopt the 640×480 gray scale image in Fig. 2(a). Fig. 2(b) and Fig. 2(c) are processed by the conv-1 [3] and the proposed methods. Futhermore, Fig. 2(d)–(f) are the zoomed parts of images Fig. 2(a)–(c), respectively. Fig. 3 compares the processing times of the conv-1 [3], conv-2 [1], and the proposed methods. Fig. 4 also shows quality of the image restoration using five grade MOS with ACR [4] for the conv-1 [3], conv-2 [1], and proposed methods. From above, we see that the proposed method indicates a better restoration effect and restores the original image than the conv-1 [3] and conv-2 [1]. Additionally the proposed method achieves fast image restoration without sacrificing the quality of the original image.

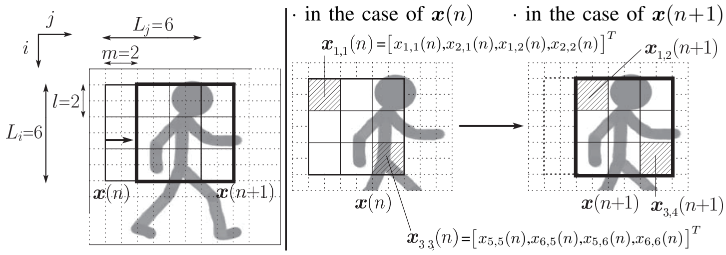

Fig. 1: Propagation of the state.

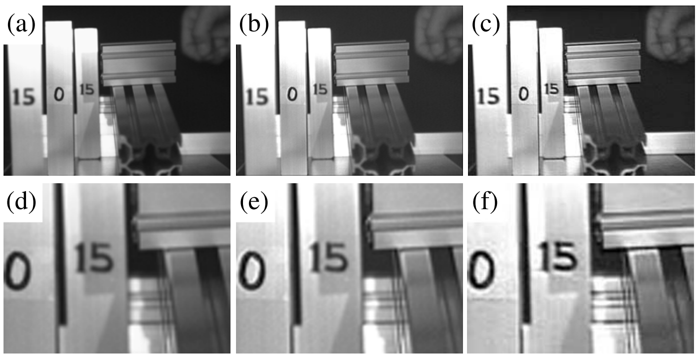

Fig. 2: Image restoration. (a) original image. (b) restored using the conv-1 [3]. (c) restored using the proposed method. (d)–(f) are the zoomed parts of images (a)–(c), respectively.

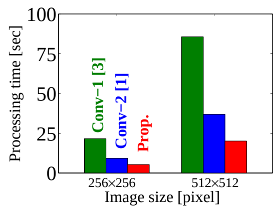

Fig. 3: Processing times [3]

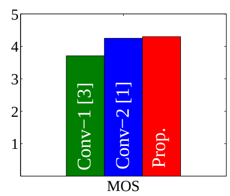

Fig. 4: Mean opinion score [4]

IV. Conclusions

This paper presented a fast image restoration using the 2-D block Kalman filter with colored driving source. We have also shown by computer simulation that the proposed method is fairly effective.

References

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