Information Sciences 354 (2016) 112–130

Contents lists available at ScienceDirect

Information Sciences

journal homepage: www.elsevier.com/locate/ins

Locally estimated heterogeneity property and its fuzzy filter application for deinterlacing

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ARTICLE INFO

Article history:
Received 10 March 2015
Revised 29 January 2016
Accepted 6 March 2016
Available online 18 March 2016

Keywords:
Deinterlacing
Fuzzy-based weighted average filter
Variance estimation
Window characteristic
Intensity similarity
Geometric closeness

ABSTRACT

This paper presents an intra-field scanning format conversion method using two filters: bilinear filter (BF) and fuzzy-based weighted average filter (FWAF). The proposed method is intended for black and white images, luminance component of YIQ color space, or each color component of RGB color space. We start from the notion that pixels to be interpolated can be classified into two areas based on local variance: homogeneous and heterogeneous areas. According to the local variance criteria, we apply the FWAF to the heterogeneous area and the BF to the homogeneous one, producing good visual results. Our FWAF consists of an intensity similarity filter and a geometric closeness filter. The latter is used to populate the heterogeneous area with the missing lines, due to its high deinterlacing precision. Our experimental results show that the proposed approach provides satisfactory performances in terms of both objective metrics and visual image quality. We used parameter tuning on our training set to explore the relationship between objective quality and computational complexity. We report on how to achieve good performance or the best quality-speed tradeoff using the methods researched.

1. Introduction

The fuzzy concept-based methods can model uncertainty and subjective concepts in image processing [1]. Edge details are key factors for improving the subjective perception of an image. However, concluding whether a pixel belongs to a homogeneous or heterogeneous areas is not a trivial work. This study focuses on the development of fuzzy metric-based methods for the particular task of video deinterlacing. Present digital television transmission formats use an interlaced scan mode. The high-definition television (HDTV) broadcasting system, such as ATSC and DVB, accepts an interlaced scanning format (1080*i*, 1080 × 1920 resolution with only 540 lines scanned in each frame) [2], where '*i*' stands for interlaced scanning. Interlaced scanning is directly compatible with some CRT-based HDTV sets where video can be displayed natively in interlaced form, but for display on modern progressive-scan LCD and PDP sets, video must be deinterlaced and in many cases, scaled to the display resolution.

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http://dx.doi.org/10.1016/j.ins.2016.03.016

Interlaced scan fields contain half the samples of the original signal, and only the even or odd lines of a frame are scanned and displayed serially. The idea of interlaced scan was considered in the first place because of a well-known fact of human physiology: the human visual system is more sensitive to flicker, serration and line crawl when screens get bigger and brighter, and the frame rate become higher [3,4]. As displays become larger and brighter, there is a necessity for conversion between interlaced and progressive scanning formats. The purpose of interlaced scanning is to accomplish a tradeoff between the frame rate and transmission bandwidth requirements [5]. The conversion process from interlaced fields into progressive frames is called *deinterlacing*.

Conventional deinterlacing populates the missing lines in two ways: intra-field methods and inter-field methods. Inter-field methods can be further categorized into non-motion compensated (NMC) and motion compensated (MC) methods [6–11]. Inter-field methods use not only current field but also neighbor frames, and as a result they provide better image quality with less motion scenes. However, the NMC methods are not able to correctly deinterlace sequences with high spatial motion frequencies. As the human visual system is very sensitive to details, even a single badly interpolated edge may considerably lower the visual quality of the results. In turn, MC methods provide good results in general. However, due to processing motion information, higher complexity than the intra-field methods and NMC. Intra-field methods need less computational resources than motion-based inter-field methods because they only use the current field and are therefore, more reliable for real-time applications.

Intra-field methods can be classified into two categories: edge direction-based and filter-based methods. The former compute dominating edge direction along which to deinterlace with a skewed line average filter. Some examples of edge direction-based methods are edge map-based deinterlacing (EMD) [12], low-complexity interpolation method for deinterlacing (LCID) [13], modified ELA (MELA) [14], deinterlacing using locally adaptive-threshold binary image (LABI) [15], and fine edge-preserving deinterlacing (FEPD) [16]. However, all edge direction-based approaches suffer from occasional low performance as a result of incorrect directional estimation or the limitations of direction models in high spatial frequency areas or horizontal edges. EMD, LCID, MELA, and FEPD sometimes yield incorrect edge direction because they consider only horizontal and vertical gradients to compute the local edge direction. The LABI method provides noticeable improvements on the specific regions where horizontal edges exist, but is computationally heavy due to its large search range.

The other category is filter-based methods. Some examples of this category are modified covariance-based adaptive deinterlacing (MCAD) [17], local surface model-based deinterlacing (LSMD), and least squares method based frequency domain filter-based deinterlacing (FFD). As long as the similarity between the high-resolution covariance and the low-resolution covariance is firmly settled, the optimal linear interpolation coefficients for minimum mean squared error (MSE) can be extracted by the classical Wiener filter (MCAD and LSMD) and least squares filter (FFD). However, the major drawback of MCAD and LSMD is their pricey computational complexity. To alleviate this issue, FFD computes filter coefficients before the implementation of deinterlacing by pre-processed training. However, the obtained filters do not always guarantee the minimum MSE results.

In this paper, we present our novel intra-field deinterlacing method. We first classify pixels into two regions, homogeneous and heterogeneous, using local variance criteria. The area with higher local variance is called *heterogeneous* and a novel fuzzy-based weighted average filter (FWAF) is applied to it. In turn, the area with lower local variance is designated as *homogeneous* and a bilinear filter (BF) is applied to it. FWAF consists of intensity similarity filter and geometric closeness filter, which is employed to interpolate the missing pixels. Finally, all weights assigned to neighbor pixels are considered for populating the missing pixels.

This paper is organized as follows. Our proposed method is described in Section 2, where the fuzzy filter approach, the variance estimation method for local windows, and the implementation of deinterlacing are explained. In Section 3, experimental results and performance analyses are discussed to show the reliability of the proposed method. Finally, Section 4 draws our conclusions.

2. Proposed algorithm

2.1. Filter-based approach

In this paper, we focus on an intra-field method which belongs to the NMC category and provides good performance with low complexity. The bilinear interpolation (Bob) method uses a single field to restore a progressive frame along orthogonal (90°) edge directions. The edge-based method uses the uniform weighted sum of 2-Tap Filter (2TF), $h_{2TF} = [1\,1]/2$, to reconstruct the missing pixel along a determined edge direction. The frequency response of 2TF looks like a bell shape as shown in Fig. 1(a). For this reason, high frequency information is not well restored, and 2TF may cause apparent jaggedness at the edges of the area.

The *sinc* function defines an ideal filter whose frequency response is a rectangular shape, with vertical frequency cuts. Based on this function, we can design a real filter having a steeper frequency cuts than the 2TF, so interlaced signals can be reconstructed more accurately. In [18], the authors adopted *sinc* filter, which is a 1D 6-Tap Filter ($h_{6TF} = [3\ -17\ 78\ 78\ -17\ 3]/128$) as shown in Fig. 1(b). Coefficients of 'h_{6TF}' are determined by approximating the *sinc* function.

We remark that this is the same method used in HEVC to decrease residual errors. However, this method only deals with similarity of *sinc* function, and topological parameters like closeness or spatial locality are not taken into account.