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Resolution enhancement of video sequences by using discrete wavelet transform and illumination compensation

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Abstract

This research paper proposes a new technique for video resolution enhancement that employees an illumination compensation procedure before the registration process. After the illumination compensation process, the respective frames are registered using the Irani and Peleg technique. In parallel, the corresponding frame is decomposed into high-frequency (low-high, high-low, and high-high) and low-frequency (low-low) subbands using discrete wavelet transform (DWT). The high-frequency subbands are superresolved using bicubic interpolation. Afterwards, the interpolated high-frequency subbands and superresolved low-frequency subband obtained by registration are used to construct the high-resolution frame using inverse DWT. The superiority of the proposed resolution enhancement method over well-known video superresolution techniques is shown with quantitative experimental results. For the Akiyo video sequence, there are improvements of 2.26 dB when compared to the average peak signal-to-noise ratio obtained by the state-of-the-art resolution technique proposed by Vandewalle.

Key Words: *Video resolution enhancement, image processing, wavelet transform, illumination compensation*

1. Introduction

Mobile phones are one of the most commonly used tools in daily life and many people record videos of various events using the phones' embedded cameras. Due to the low resolution of the cameras, viewing these videos on

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high-resolution screens is usually not very pleasant. That is one of the reasons why resolution enhancements of low-resolution video sequences are at the center of interest for many researchers. According to the research conducted in the field of superresolution, enhancing resolution can be done in 2 ways. The first method is known as multiframe resolution enhancement. In this method, information obtained from several frames in a video sequence is combined [1]. The second approach is single-frame resolution enhancement. In this method, prior training data are used to enhance the resolution of one low-resolution frame or image. In the current paper, we follow the multiframe resolution enhancement.

The earlier idea of superresolution, in which the frequency domain approach was used, was proposed by Tsai and Huang [2]. Further research was conducted by Keren et al. [3]. Moreover, Reddy and Chatterji [4] proposed a frequency domain method for resolution enhancement. Afterwards, Lucchese and Cortelazzo [5] presented a method in the frequency domain. A motion estimation algorithm was introduced by Irani and Peleg [6]. Their proposed technique considered rotations and translations in the spatial domain. Meanwhile, further research has been done on developing superresolution [7-11]. Vandewalle et al. proposed a state-of-the-art technique in which a frequency-domain technique was considered for registering aliased images [12].

One of the most common tools used in image processing, especially in resolution enhancement techniques, is the wavelet transform [13-17]. A 1-level discrete wavelet transform (DWT) of a video sequence's frame produces a low-frequency subband known as low-low (LL), and 3 high-frequency subbands, low-high (LH), high-low (HL), and high-high (HH), oriented at horizontal (0°), diagonal (45°), and vertical (90°) angles [18].

In this paper, a video superresolution method is proposed. This resolution enhancement technique uses DWT in order to decompose low-resolution input frames. The LH, HL, and HH subbands of the frames are superresolved using bicubic interpolation. At the same time, the input low-resolution frames are superresolved using the Irani and Peleg technique [6]. Illumination inconsistence can be attributed to uncontrolled environments. Because the Irani and Peleg registration technique is used, it is an advantage that the frames used in the registration process have the same illumination. In addition, in this paper, a new illumination compensation method using singular value decomposition (SVD) is proposed. The illumination compensation technique is applied to the frames as the preprocessing stage, and then the Irani and Peleg resolution enhancement technique is implemented on the processed frames. Finally, inverse DWT (IDWT) is used to combine the interpolated high-frequency subbands, obtained from the DWT of the corresponding frames, and their respective superresolved input frames to reconstruct a superresolved video sequence. For comparison purposes, the methods of Keren et al. [3], Lucchese and Cortelazzo [5], Marcel et al. [8], and Vandewalle et al. [12] were used for registration, followed by various reconstruction techniques such as the robust superresolution technique [19], bicubic interpolation, iterated back projection [6], and structure adaptive normalized convolution [20].

The experimental results conducted in this study show that the proposed resolution enhancement technique performs better than the above superresolution techniques. Moreover, as it will be shown in the experimental section, the proposed illumination compensation improves the quality of the process by 2.26 dB in the peak signal-to-noise ratio (PSNR) for the Akiyo video sequence.

2. Proposed resolution enhancement technique

As was mentioned in the previous section, there are various resolution enhancement methods. The smoothing of high-frequency components, or in other words the edges, of a video frame within the resolution enhancement process is the main loss of the superresolved frame. Furthermore, in many video superresolution methods, slight illumination changes of the successive frames due to movements can cause poor registration. This causes a decrease in the quality of the output sequence. Hence, not only preserving the high frequencies of each frame but also enhancing the illumination can positively affect the quality of the output sequence.

In the present study, the Irani and Peleg registration technique is applied for registration using 4 successive frames at each stage. The frames can be named f_0, f_1, f_2, and f_3, in which f_1 is the reference frame that is aimed to be superresolved. The illumination difference between f_0, f_2, and f_3 and f_1 is reduced by applying the proposed illumination compensation technique. The illumination enhancement technique using SVD [21] is employed iteratively for compensating the illumination. Here, a threshold value, τ, indicates the number of iterations. This threshold value is equal to the illumination difference between the reference frame and the corresponding frame, and it is chosen according to the application. In this paper, τ is heuristically chosen as 0.2. The aim of the illumination correction technique is to enhance the illumination of frames f_0, f_2, and f_3 in order to have the same illumination as the reference frame. Thus, SVD is used to decompose each frame into 4 matrices:

$$f_i = U_i \Sigma_i V_i^T \quad i = 0,\ 1,\ 2,\ 3. \tag{1}$$

Here, Σ is a matrix containing the sorted eigenvalues of f on its main diagonal containing the intensity information of the given frame [14,21]. The first singular value of the Σ matrix, σ_1, is the largest singular value, which is why manipulating σ_1 will affect the illumination of the frame. Hence, the objective is to enhance the largest singular value close enough to that of the reference frame in order to obtain an illumination similar to that of the reference frame. Therefore, a coefficient is calculated by using:

$$\xi_{f_j} = \frac{\max\left(\Sigma_{f_1}\right)}{\max\left(\Sigma_{f_j}\right)} \quad j = 0, 2, 3. \tag{2}$$

Thus, a new enhanced frame is obtained by:

$$f_{\text{enhanced } j} = U_j \left(\xi_j \Sigma_j\right) V_j^T \quad j = 0, 2, 3. \tag{3}$$

Because quantization will take the place after the enhanced frame is obtained, the σ_1 value that is obtained from Eq. (1) after some iteration will vary slightly from that on the right side of Eq. (3). The flow diagram of the illumination enhancement technique is illustrated in Figure 1.

Figure 2 shows the convergence of the pixel average of 2 of the frames towards the reference frame for the Akiyo video sequence in progressive iterations.

In this paper, the high-frequency components of each frame are preserved using DWT [18]. The 1-level DWT process for each frame generates 4 video sequences. In parallel to the DWT process, the Irani and Peleg superresolution technique [6] is applied to the input sequences in the spatial domain. The resolution-enhanced frame is obtained using this process and it is regarded as a LL subband of a higher (target) resolution frame. The high-frequency subbands of the higher (target) resolution frames are generated by the interpolation of the previously extracted LH, HL, and HH subbands from the input reference frames. Finally, IDWT is employed to reconstruct the superresolved output frame.

The sharpness of the output video sequence is due to the superresolving of the different subbands of the input low-resolution sequences and the application of IDWT. This is due to the separation of the high-frequency components (edges) from the low-frequency ones, which preserves more edges.

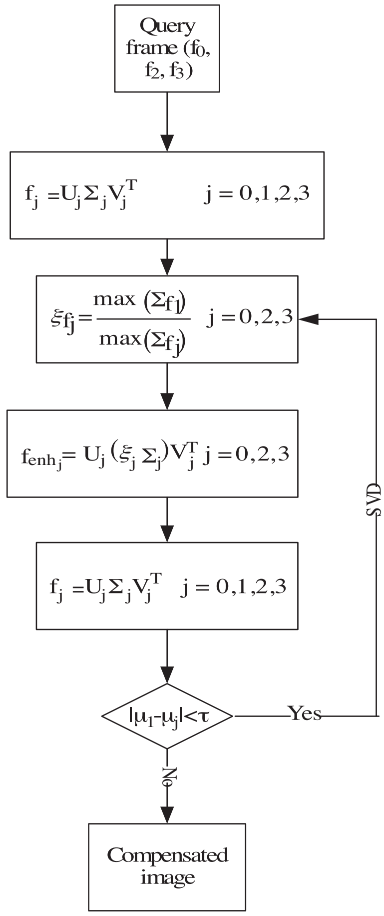

Figure 1. The proposed illumination compensation technique.

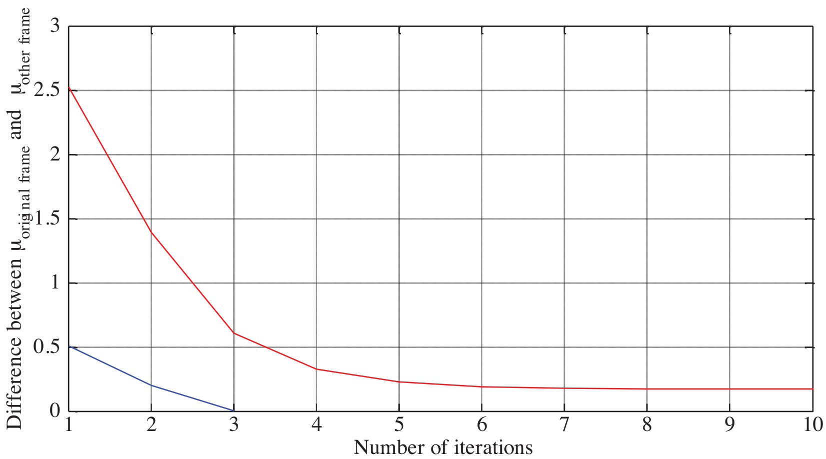

Figure 2. The convergence of the mean of the first (blue) and the third (red) frames of the Akiyo sequence to the mean of the second frame (reference).

The following steps can summarize the proposed resolution enhancement technique:

1. Acquire frames from a video.

2. Apply the proposed illumination compensation technique before registration.
3. Apply DWT to the input video sequence.
4. Superresolve the original corresponding frame by applying the Irani and Peleg superresolution technique.
5. Apply bicubic interpolation to the extracted high-frequency subbands.
6. Apply IDWT to the output of step 4 and 3 outputs of step 5 in order to reconstruct the high-resolution video sequence.

In the fourth step, 4 illumination-compensated consecutive frames are used for registration in the implementation of the Irani and Peleg technique. Figure 3 shows the block diagram of the proposed video superresolution technique.

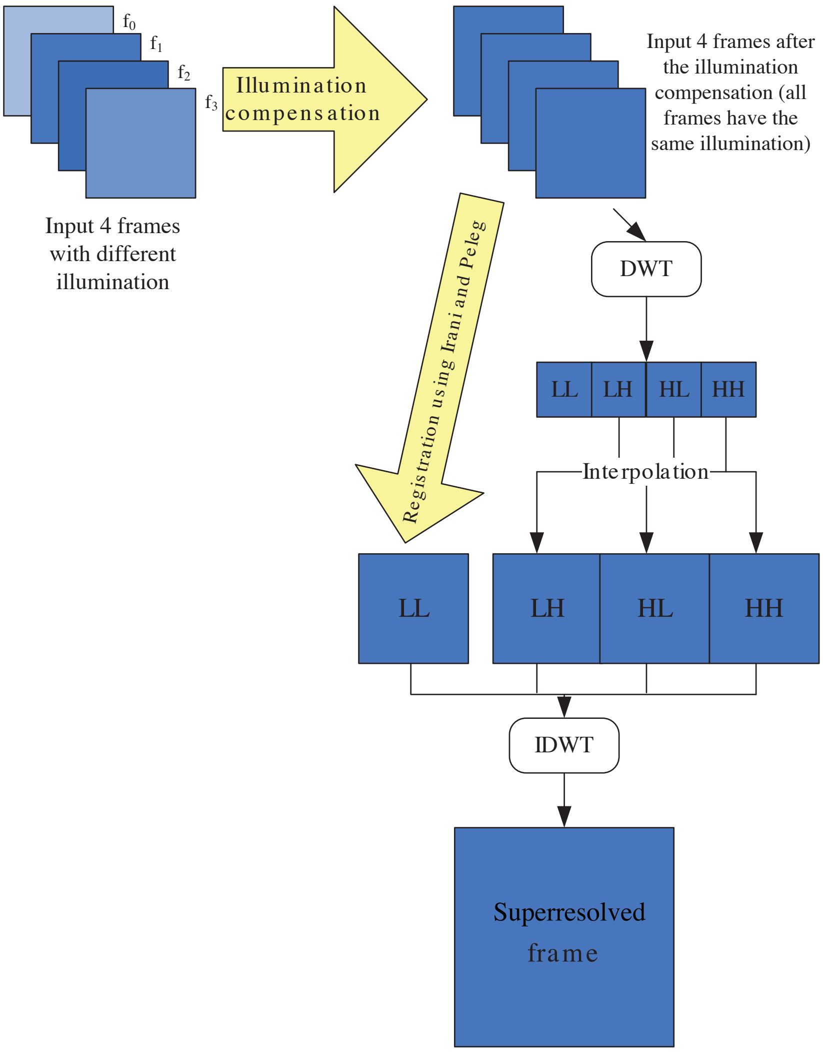

Figure 3. The flowchart of the proposed technique for resolution enhancement.

A possible application of the proposed resolution enhancement technique is that if someone is holding his or her digital camera while quickly taking a series of 4 snapshots, the small translation of the person's hands while capturing the snapshots may cause some illumination changes sufficient to reconstruct the superresolved image.

The db.9/7 wavelet function and bicubic interpolation are used in our experiments in this research work. In the following section, the experimental results and comparisons between the proposed resolution enhancement technique and various well-known techniques are presented and discussed. The quantitative results (PSNR) show the superiority of the proposed resolution enhancement technique over the aforementioned techniques.

3. Experimental results

In this paper, we compare the proposed resolution enhancement technique with several well-known superresolution techniques, namely those of Lucchese and Cortelazzo [5], Marcel et al. [8], Vandewalle et al. [12], and Keren et al. [3], for the registration and robust superresolution, structure-adaptive normalized convolution, interpolation, and iterated back projection techniques for reconstruction. Four well-known video sequences [22], Akiyo, Container, Foreman, and Mother-Daughter, are used for conducting the experiments. The Table shows the PSNR values of the different superresolution techniques.

The low-resolution video sequences, as reported in [23], do not contain the quantization error. The above video sequences contain 300 frames each, and the averages of the 300 PSNR values for each frame are reported

Table. The average of 300 PSNR (dB) values for different sequences obtained by using various superresolution techniques.

Superresolution technique		Average PSNR (dB) Value			
Registration	Reconstruction	Mother-Daughter	Akiyo	Foreman	Container
Vandewalle	Interpolation	24.29	29.45	28.01	23.6
	Iterated back projection	27.1	31.49	30.17	24.3
	Robust superresolution	27.15	31.5	30.24	24.46
	Structure-adaptive normalized convolution	28.95	32.98	33.46	26.38
Marcel	Interpolation	24.44	29.6	28.16	24.96
	Iterated back projection	27.12	31.52	29.84	25.2
	Robust superresolution	27.18	31.54	30.24	25.25
	Structure-adaptive normalized convolution	28.66	33.16	33.25	26.28
Lucchese	Interpolation	24.1	29.62	28.19	24.53
	Iterated back projection	27.06	31.52	29.88	25.28
	Robust superresolution	27.13	31.55	30.29	25.31
	Structure-adaptive normalized convolution	29.01	32.8	33.3	26.36
Keren	Interpolation	23.16	29.6	28.17	24.78
	Iterated back projection	27.17	31.53	29.87	25.31
	Robust superresolution	27.2	31.55	30.29	25.46
	Structure-adaptive normalized convolution	28.63	32.97	33.25	26.15
Proposed superresolution technique without illumination compensation		31.53	34.07	35.87	28.94
Proposed superresolution technique with illumination compensation		**32.17**	**35.24**	**36.52**	**30.07**

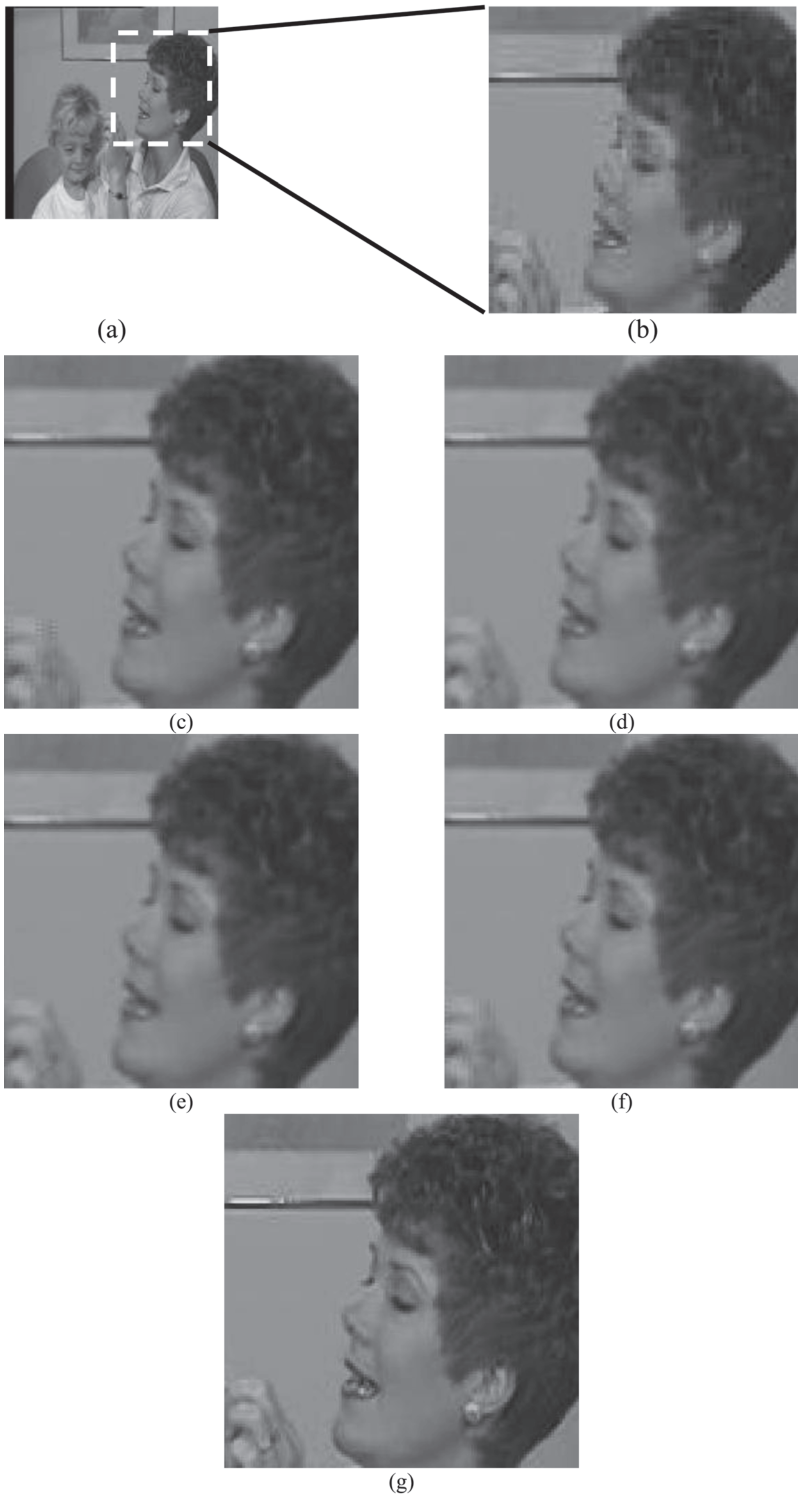

Figure 4. The visual representation of a frame of a low-resolution ‘mother-daughter’ video sequence (a) and a zoomed segment of the frame (b), and the superresolved frame using the Keren (c), Lucchese (d), Marcel (e), and Vandewalle (f) registration techniques and the proposed technique (g).

in the Table. In the conducted experiment, the 128 × 128 low-resolution video sequences are used as the input and the size of the superresolved frames is 256 × 256.

Figure 4 demonstrates the visual result of the proposed method compared with other well-known techniques for 'mother-daughter' sequences. As is observed in Figure 4, the proposed method results in a sharper image compared with the other well-known superresolution techniques.

4. Conclusion

A new video resolution enhancement technique was proposed by applying a preprocessing stage for the illumination compensation technique and using DWT. The output of the Irani and Peleg technique was used as the LL subband, in which the LH, HL, and HH subbands were obtained by interpolating the former high-frequency subbands. Afterwards, IDWT was used to generate a respective superresolved frame. Enriched comparisons between the proposed technique and various well-known superresolution techniques were conducted and the quantitative results showed the superiority of the proposed technique.

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