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A multi-model restoration algorithm for recovering blood vessels in skin images☆

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ABSTRACT

Blood vessels under skin surface have been used as a biometric trait for many years. Traditionally, they are used only in commercial and governmental applications because infrared images are required to capture high quality blood vessels. Recent research results demonstrate that blood vessels can be extracted directly from color images potentially for forensic applications. However, color images taken by consumer cameras are likely compressed by the JPEG compression method. As a result, the quality of the color images is seriously degraded, which makes the blood vessels difficult to be visualized. In this paper, a multi-model restoration algorithm (MMRA) is presented to remove blocking artifacts in JPEG compressed images and restore the lost information. Two mathematical properties in the JPEG compression process are identified and used to design MMRA. MMRA is based on a tailor-made clustering scheme to group training data and learns a model, which predicts original discrete cosine transform coefficients, from each grouped dataset. An open skin image database containing 978 forearm images and 916 thigh images with weak blood vessel information and a set of diverse skin images collected from the Internet are used to evaluate MMRA. Different resolutions and different compression factors are examined. The experimental results show clearly that MMRA restores blood vessels more effectively than the state-of-the-art deblocking methods.

1. Introduction

Because of the recent advances of imaging technology, the number of evidence images, e.g., child pornographic images, is increasing dramatically [1–3]. Criminals in some of these images, e.g., pedophiles, usually show only skin with neither faces nor tattoos to avoid identification. This identification problem is not limited to child sexual abuse cases, but also includes masked gunmen, riots and terrorist attacks. Most of the traditional biometric traits, including face, fingerprint, DNA and palmprint are not applicable to these evidence images. Skin marks, scars, and androgenic hair patterns give valuable information for identifying the criminals [4–7]. However, they are insufficient to address the problem. Not every criminal has a unique scar, skin mark or androgenic hair pattern on a particular body site exposed in the images.

Hand veins, palm veins and finger veins have been widely studied for development of commercial biometric systems because they can be captured in contactless environments and are difficult to be forged [43–44]. Vein patterns are generally considered as a hard biometric trait. Infrared and laser imaging systems are required to capture this vascular information under skin, because they have high penetration ability, comparing to visible light. Recently some researchers attempt to visualize blood vessels hidden in color images for commercial biometric, healthcare and forensic applications [8–11]. Their results exposed the potential of using blood vessels for criminal and victim identification. However, most of evidence images in the cases mentioned above are taken by consumer cameras and compressed by the JPEG method [12]. Vascular information hidden in images can be seriously degraded by the JPEG method, which makes the visualization methods not work. Fig. 1 shows three images collected from the Internet as examples. The first column shows the original color images[1]. The second column shows the corresponding visualized blood vessels [10]. The third and the last columns show their visualized blood vessels from the JPEG compressed versions with compression factors of 75 and 50 respectively. Blood vessels from the original images (the second column) are clear, but they are seriously degraded by the JPEG method (the third and last columns). Thus, to finally utilize blood vessels for identifying criminals and victims or searching suspects, vascular information should be restored before applying the visualization methods.

Though many deblocking methods have been proposed, they are not suitable to restore vascular information because they are designed for

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[1] The images were downloaded from the Internet and were originally compressed by JPEG method. To show the degradation effects, original (uncompressed) images were required. Thus, the downloaded images were resized to remove the compression effects and referred to as references.

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0262-8856/

Fig. 1. Illustration of vascular information degraded by the JPEG method. The first column is three original images collected from the Internet. The second column is the corresponding blood vessel patterns visualized by Zhang et al.'s method [10]. The third and the last columns show their visualized blood vessels from the JPEG compressed versions with compression factors of 75 and 50 respectively.

generic images. These methods attempt to remove blocking artifacts, but original information is not guaranteed to be restored. Some priors are imposed on some of these methods. However, they are not related to blood vessel quality. In fact, many of them further deteriorate the vascular information, which is already weakened by the JPEG method. An effective blood vessel restoration method should recover the original information and suppress the blocking artifacts as well. In this paper, statistics of skin images and mathematical properties in the JPEG method are used to design the proposed algorithm, multi-model restoration algorithm (MMRA), to remove blocking artifacts and recover blood vessels from JPEG compressed skin images. MMRA is an application-specific method [13–17], which uses prior knowledge from the JPEG compression process to cluster training sets and learn a model for each clustered dataset to perform restoration.

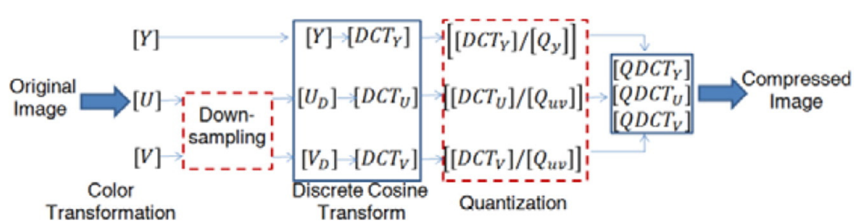
The rest of this paper is organized as follows. Section 2 briefly introduces the JPEG method and previous deblocking methods. Section 3 presents the proposed algorithm. Section 4 reports the experimental results and comparisons. Section 5 offers some concluding remarks.

2. The JPEG method and related works

The main steps of the JPEG method are illustrated in Fig. 2(a). Images are first transformed from the RGB color space into the YUV color space. The three channels are processed separately in the rest of the operations. As human vision is less sensitive to the chrominance channels, the U and V channels are down-sampled. Then, the three channels are divided into 8 by 8 blocks and each block is processed by the discrete cosine transform (DCT). The quantized DCT (QDCT) coefficients are computed by,

$$x_{zk}^{j} = \left[y_{zk}^{j} / q_{zk} \right], \qquad (1)$$

where y_{zk}^{j} denotes the k^{th} DCT coefficient in the j^{th} block and the z channel; q_{zk} is a value from a predefined quantization table, Q_z; $k \in \{1, 2, \cdots, 64\}$; $z \in \{Y, U, V\}$ and [ ] is a round operator. Finally, the QDCT coefficients are encoded to increase compression ratio without



(a)

1	2	6	7	15	16	28	29
3	5	8	14	17	27	30	43
4	9	13	18	26	31	42	44
10	12	19	25	32	41	45	54
11	20	24	33	40	46	53	55
21	23	34	39	47	52	56	61
22	35	38	48	51	57	60	62
36	37	49	50	58	59	63	64

(b)

16	11	10	16	24	40	51	61
12	12	14	19	26	58	60	55
14	13	16	24	40	57	69	56
14	17	22	29	51	87	80	62
18	22	37	56	68	109	103	77
24	35	55	64	81	103	113	92
49	64	78	87	103	121	120	101
72	92	95	98	112	100	103	99

(c)

17	18	24	47	99	99	99	99
18	21	26	66	99	99	99	99
24	26	56	99	99	99	99	99
47	66	99	99	99	99	99	99
99	99	99	99	99	99	99	99
99	99	99	99	99	99	99	99
99	99	99	99	99	99	99	99
99	99	99	99	99	99	99	99

(d)

Fig. 2. Introduction to the JPEG method. (a) is an illustration of the JPEG method. (b) is the zigzag order. (c) is the quantization table Q_y for the Y channel with a quality factor of 50 and (d) is the quantization table Q_{uv} for the U and V channels with a quality factor of 50.