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An efficient forgery detection algorithm for object removal by exemplar-based image inpainting ☆

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ABSTRACT

As a popular image manipulation technique, object removal can be achieved by image-inpainting without any noticeable traces, which poses huge challenges to passive image forensics. The existing detection approach utilizes full search for block matching, resulting in high computational complexity. This paper presents an efficient forgery detection algorithm for object removal by exemplar-based inpainting, which integrates central pixel mapping (CPM), greatest zero-connectivity component labeling (GZCL) and fragment splicing detection (FSD). CPM speeds up suspicious block search by efficiently matching those blocks with similar hash values and then finding the suspicious pairs. To improve the detection precision, GZCL is used to mark the tampered pixels in suspected block pairs. FSD is adopted to distinguish and locate tampered regions from its best-match regions. Experimental results show that the proposed algorithm can reduce up to 90% of the processing time and maintain a detection precision above 85% under different kinds of object-removed images.

1. Introduction

The prevalence of powerful image processing softwares and the advancement in digital cameras have given rise to large amounts of doctored images with no obvious traces, triggering a great demand for automatic forgery detection algorithms that can identify the trustworthiness of a candidate image [1]. Especially, passive image forensics has attracted great research interests since it does not require any auxiliary data such as watermarks or signatures [2,3]. Up to present, there are extensive works for the passive forensics of various tampering such as sub-sampling [4], double jpeg compression [5] and median filtering [6].

For digital images, the manipulations of image objects including object adding, removing or modifying are of the most attention because these changes of objects will directly mislead the understanding and awareness of the image content. In general, image object removal techniques can be grouped into two categories [2]: copy-move and image inpainting. Copy-move is achieved by copying a region from an image and then pasting it into the same image with the intent of hiding undesired objects [3]. Due to its simplicity, copy-move has become the most widely used method for manipulating the semantics of an image. Recently, extensive researches have been done on the passive forensics against copy-move and a series of detection algorithms have been presented [7–13].

In the past few years, image inpainting has made great progress and is now playing an important role in contents correction and image restoration. However, it can also be a useful tool for object removal [2]. Inspired by real techniques for painting restoration, image inpainting methods fill the holes left by object removal through exploiting the information preserved in the surrounding regions. Object removal achieved by image inpainting can preserve texture and structure continuity [14]. As a result, it leaves no obvious traces of tampering, which makes passive image forensics extremely challenging. Up to now, little study has been done on passive forensics for image inpainting, among which there are three representative works. As a first attempt, Wu et al. [15] proposed a passive forensics method to discriminate natural images from inpainted images, which used zero-connectivity labeling to yield matching degree of the blocks in suspicious regions and computed the fuzzy memberships to identify the tampered regions by a cut set. However, it is a semi-automated detection method which requires to manually select a region of suspicion in advance. Moreover, the algorithm seeks for suspicious blocks by means of full search, resulting in high computation complexity. Later, Bacchuwar and Ramakrishnan [16] devised an improved method

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based on the luminance component of the image and median comparison of the blocks in the region of suspicion. The improved approach converted the image to YUV space and only the Y component was used to search for suspicious blocks. Before calculating matching degree of block pairs, the medians of blocks were compared. If the difference was great enough, the calculation of matching degree would be skipped. Though the simplified method can reduce processing time to some extent, it is still a semi-automatic approach. In order to overcome the shortcoming of abovementioned methods, Chang et al. [17] presented an automatic forgery detection algorithm for exemplar-based inpainting images using multi-region relation. In this method, zero-connectivity feature was also used to search for suspicious blocks and vector filtering was exploited to remove the false-alarmed blocks located in the uniform background. Besides, three types of regions were produced according to the relationships among suspicious regions: multi-link, single-link and self-link, while only the multi-link regions were regarded as tampered. Furthermore, weight-transformation based mapping approach was adopted to accelerate the search of suspicious blocks. In spite of outperforming the former two methods in terms of computational efficiency, weight-transformation based mapping approach cannot optimize load factor and search range simultaneously, which thereby constrains further improvement of search speed and detection accuracy. Therefore, we propose an improved passive forensics method, which enables an optimization between the load factor and the search range.

This paper proposes an efficient passive forgery detection method for object removal by exemplar-based inpainting using central pixel mapping (CPM), greatest zero-connectivity component labeling (GZCL) and fragment splicing detection (FSD). As compares to the current state of the art [15–17], the contributions of this paper are as follows: Firstly, CPM is proposed to speed up suspicious block search, which assigns hash value for target block according to the color information of central pixel and then searches for the best-match block among those with similar hash values. The hash values obtained from CPM can better represent the color distributions of image blocks, producing a higher aggregation of similar blocks, which further narrowing the search range. Meanwhile, CPM generates one to one mapping between image blocks and hash values, so that the load factor of the hash table is more close to 1, thus the search efficiency is further improved. Above all, CPM enhances search performance in terms of both load factor and search range. Secondly, GZCL is adopted to mark the tampered pixels in suspicious blocks. After searching the suspicious blocks, the existing methods directly label all the pixels in suspicious block as being tampered, which will lead to higher false alarm and a jagged edge of the detected region. In order to improve detection precision, GZCL takes advantage of the greatest zero-connectivity component in the difference array and marks the corresponding pixels within the suspicious block as being tampered, through which not only a smoother edge is obtained but also the false positive rate will be reduced. Thirdly, FSD is used to distinguish tampered regions from reference regions and obtain the final position of forgery. Most existing algorithms consider both reference and tampered regions as being forged, which makes the reference regions to be another reason of false alarm. In order to solve this problem, FSD calculates the number of regions matched with the target region and filters out those with less matched regions, resulting in a higher detection precision. Experimental results show that the proposed algorithm can reduce 90% of processing time and keep false alarm lower than 15%.

The rest of this paper is organized as follows: Section 2 briefly introduces the image inpainting techniques, particularly exemplar-based inpainting. Section 3 describes the proposed detection method. Section 4 focuses on the fast search algorithm based on central pixel mapping. Section 5 presents the experimental results and analysis. Finally, we conclude in Section 6.

2. Image inpainting

Image inpainting is a technique used for image restoration that can recover the lost information in old photographs and remove scratches in images. However, it could also be exploited to remove image semantic objects for malicious motives. In this case, image inpainting becomes a forgery manipulation. Before we go into details about forensics against inpainting based object removal, it is necessary to briefly introduce the principles of image inpainting and analyze the possible traces left behind.

Based on their application in image restoration, inpainting techniques can be mainly divided into two categories [14]. One is pixel-based approaches [18–20], which are mainly focused on structural repairing and used to repair small-scale defects (such as cracks, and scratches). However, it will generate obvious blur when the damaged region is large or the texture is rich. The other one is exemplar-based approaches [21–23], which combine structure recovery with texture repairing and can be used to restore larger loss of information in the image. Criminisi's algorithm [21] is among the most popular exemplar-based inpainting approaches. Many researchers have exploited the inpainting framework in Criminisi's algorithm due to its good visual effect. Therefore, we take Criminisi's algorithm as an example and introduce the principle of exemplar-based inpainting.

Before inpainting, users need to select target region to be removed and filled, as shown in Fig. 1(a). The target region is indicated by Ω, and its contour is denoted by $\partial\Omega$ and the source region, Φ, may be defined as the entire image minus the target region. Then the inpainting procedure is conducted as follows.

1. Compute the priorities of the points along $\partial\Omega$ and find the point p with highest priority. Then, the block Ψ_p centered at the point p is selected as target block, as shown in Fig. 1(b).
2. Search for the reference block Ψ_q which is most similar to Ψ_p in source region Φ, as shown in Fig. 1(c).
3. Fill the area to be inpainted in Ψ_p using the corresponding pixels of Ψ_q, and update the priorities among Ψ_p as well as $\partial\Omega$, as shown in Fig. 1(d).
4. Repeat step 1 to step 3 until the target region is entirely filled.

By integrating texture synthesis with pixel-based approaches, the algorithm performs well in terms of both perceptual quality and efficiency. Subsequently, there are some improvements on Criminisis algorithm, which mostly concentrate on improving priority calculation and optimizing patch searching method [22,23]. Liu and Caselles [22] proposed a novel inpainting method based on multi-scale Graph Cuts, which ensured the continuity of reconstruction at the boundary of the inpainted region as well as visually coherent reconstruction inside the hole. Wang et al. [23] introduced a regularized factor into the confidence term to lessen descending effect, which significantly improved the filling order. Meanwhile, for the condition when multiple candidates were found during the best-match reference block searching, a two-round search strategy based on a modified sum of squared differences (SSD) and normalized cross correlation (NCC) was proposed to make the inpainting more robust to images with large removal regions.

Although there are differences in ways of calculating priority and searching for best-match block between Criminisi's algorithm and improved algorithms, filling the target block with its best-match block will introduce abnormal similarity. However, there exists large amount of irregular pieces in natural images, which