Multimedia Tools and Applications (2024) 83:10445–10466
https://doi.org/10.1007/s11042-023-15866-0

Understanding digital image anti-forensics: an analytical review

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Received: 28 February 2022 / Revised: 22 February 2023 / Accepted: 15 May 2023 /
Published online: 22 June 2023

Abstract

Image forensics is essential for detecting image manipulation, authenticating images, and identifying sources of images. A forensic analyst can make use of various artifacts to develop a powerful forensic technique. These artifacts include JPEG blocking and quantization artifacts, streaking artifacts and contrast enhancement artifacts, etc. With the introduction of anti-forensics, it has become difficult for forensic experts to identify forged images. There are various anti-forensic methods available that try to eradicate these detection footprints/artifacts to fool the existing forensic detectors. Thus the detection of anti-forensic attacks is very crucial and plays a vital role in forensic analysis. This paper presents a review of various types of anti-forensic attacks, such as JPEG anti-forensics, Contrast enhancement anti-forensics, and Median filtering anti-forensics. Firstly a brief introduction is given about image forgery, JPEG compression, contrast enhancement, and median filtering. Then, anti-forensics is described in detail, and finally, the recent state-of-the-art anti-forensic techniques are summarized in tabular form for better understanding. This may be helpful for the forensic analyst to develop robust methods for forgery detection that can be applied in various applications such as the identification of cybercrimes, identity thefts, etc.

Keywords Blocking artifacts · Anti-forensics · JPEG compression · MFR · CNN

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1 Introduction

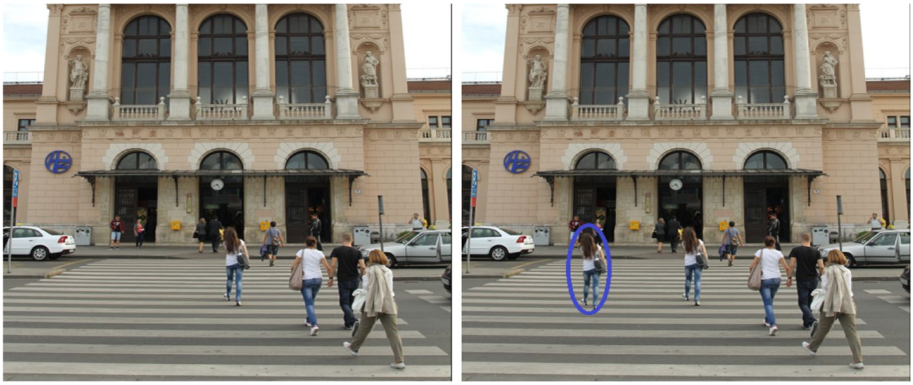
With the development of Information and Communication Technology (ICT), computers and smartphones have become essential parts of our lives. Therefore, all the data, including images, are stored in digital form. Social media platforms have become very popular for sharing information. Digital images are used to convey visual information on social media websites that spread like wildfire. But, it is easy to fabricate/manipulate a digital image with the widespread availability of powerful multimedia processing techniques and photo editing software like Adobe Photoshop, Hornil Stylepix, ACDsee, etc. Manipulated images may be used for malicious purposes, such as defaming any individual or as false evidence in a court of law. The spreading of manipulated images may even lead to communal violence or political crisis. So, it has become of paramount importance to verify the authenticity and integrity of digital images. To solve the above problem, digital image forensics comes into the picture [28]. Digital image forensics is a new research area that deals with multimedia security and mainly covers two things, source camera identification, and image forgery detection. In source camera identification, we have to identify which camera has taken a given photograph [69]. In image forgery detection, the given image is checked for any kind of modification [24]. Image forensic techniques exploit the traces left by the acquisition devices or the signal-processing operations involved in the forgery. Although there exist a large number of digital forensic techniques, most of them do not account for the possibility of anti-forensics which tries to hide the signal processing traces that are exploited in forensic analysis. Authentication of digital images in the presence of anti-forensics is a challenge for multimedia security researchers. To tackle such scenarios, it is necessary to develop powerful digital forensic techniques which can detect forgery even after the application of anti-forensics or can detect the traces left by anti-forensic operations. In [59], the Markov-based features extracted using discrete cosine transform (DCT) are combined with the local binary pattern (LBP) features to detect the manipulated images. Forensics doesn't only mean to deal with image forgery or identification of source cameras, it also refers to different areas like finger vein recognition/authentication [47], forged document detection [13] etc. Recently various deep learning techniques have been proposed for determining the authenticity of finger vein [45, 46]. The main objectives/contributions of this paper are as follows:

- To thoroughly review the anti-forensic techniques proposed in the literature, which are deliberately designed to fool existing forensic detectors.
- To help the reader to precisely draw a line between forensics and anti-forensics.
- To guide the forensic analyst to develop a robust image forgery detection technique in the presence of anti-forensic operations.

1.1 Types of image forgery

Image forgery is classified into three main types:

a) Copy-move forgery: This type of image tampering involves copying some region from a particular location in an image and pasting it at one or more places within the same image or on a different image containing the same scene [62]. An example [71] of copy-move forgery is shown in Fig. 1:
b) Image retouching: Such a forgery is obtained from the modification of the objects in terms of color or texture, intensification of the weather conditions, or introduction of



(a) Authentic image (b) Forged image

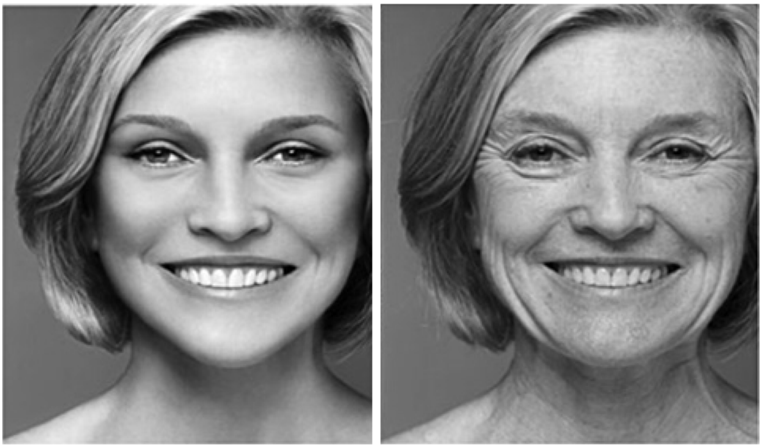
Fig. 1 Copy move forgery

blur in defusing the objects. Image retouching is illustrated with an example [72] as shown in Fig. 2:

c) Compositing or Image splicing: This type of forgery involves a process in which more than one image is combined to create a new tampered image. Image splicing is shown in Fig. 3 where authentic image 1 and authentic image 2 are used to create a forged [73] image.

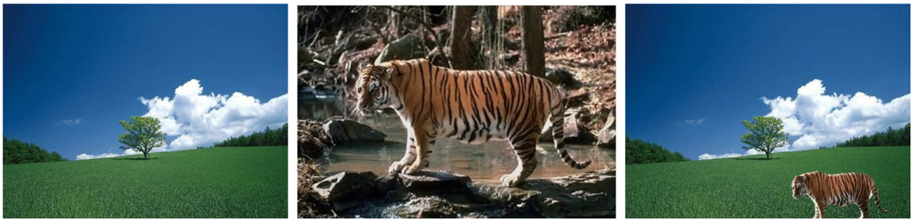
1.2 Image forensics

Digital image forensics aims to explore the authenticity of digital images by examining the accuracy of data and by restoring the past data of an image associated with its attainment stage [15, 49].



(a) Forged image (b) Authentic image

Fig. 2 Image Retouching forgery



(a) Authentic image1 (b) Authentic image2 (c) Forged image

Fig. 3 Image Splicing forgery

Image forensics techniques are broadly categorized into two types:

a) Active techniques: These include additional information that is embedded into digital images in advance. Digital watermarking is an example of an active technique where a watermark is embedded in the multimedia file during its creation. When someone attempts to manipulate the file, the watermark gets destroyed. This ensures some control over the manipulation of content in the multimedia file.
b) Passive techniques: These do not include any additional information to be embedded into digital images in advance. These techniques are also known as blind forensic techniques because they do not require prior knowledge or embedding watermarking capability.

Forensic analysis can make use of specific footprints of various image-processing artifacts. These involve JPEG compression artifacts, Contrast enhancement, Median filtering, etc.

1.2.1 JPEG compression

In JPEG compression, the image is first divided into 8×8 sized pixels of non-overlapping blocks. Further, the processing is applied to these blocks individually. Consider an 8×8 image block $A(i,j)i,\ j \in \{0...7\}$, which is modified into two-dimensional discrete cosine transform (2D-DCT). Let $B(i,j)$ be the obtained DCT coefficient which is quantized with a quantization step size $C(i,j)$. The resultant obtained quantized DCT coefficient $D(i,j)$ is given as:

$$D(i,j) = \left[\frac{B(i,j)}{C(i,j)}\right], \qquad i,j \in \{0, \cdots, 7\}. \tag{1}$$

where $[\cdot]$ denotes the integer rounding operation. Finally, entropy encoding is applied to the quantized DCT coefficients to obtain the JPEG bit-stream. A JPEG file can be translated back to the dimensional area by carrying out the inverse of the steps involved in the encoding process. The JPEG bit-stream is entropy decoded and dequantized to obtain the DCT coefficients as,

$$B'(i,j) = D(i,j) \cdot C(i,j), \qquad i,j \in \{0, \cdots, 7\}. \tag{2}$$

The steps of JPEG compression and decompression are shown in Fig. 4:

a) JPEG artifacts: There are two types of compression artifacts in JPEG forensics: Quantization artifacts and Blocking artifacts. Quantization artifacts [41] involve clustering of DCT coefficients around integer multiples of the quantization step size. In the case of multiple JPEG compression experienced by an image, the periodic pattern DCT sub-band histograms are introduced with a specific quality factor corresponding to individual compression. Blocking artifacts [17] represent pixel discontinuities across block boundaries of the decompressed image.

A JPEG image and a zoomed-in view of the JPEG image are shown in Fig. 5. It can be observed that due to the presence of blocking artifacts in JPEG images, the visual quality of the image gets degraded. The compression algorithm may be combined with encryption to provide the secured transmission/storage of data [35, 42].

1.2.2 Contrast enhancement

Contrast enhancement is the process that makes the image features stand out more clearly by making optimal use of the colors available on display. The contrast of an image can be derived from its histogram. Contrast enhancement changes the pixel values in such a way that a wide range of intensity values gets covered. Various techniques, such as histogram stretching, gamma correction, etc., are used to enhance the contrast of an image. Forgers generally blend the copied area into the target image to create a forgery. The introduction of peaks and gaps in the image histogram can then be used for contrast enhancement/forgery detection.

A Contrast Enhanced (CE) image is shown in Fig. 6.

1.2.3 Median filtering

Median filtering is a non-linear technique often used to remove noise from an image. The median filter works by rolling a window over each pixel and restoring that pixel value by a median of all the neighboring pixels, including itself, specified by the window. A forger may make use of median filtering to abolish the footprints of resampling and JPEG blocking artifacts. [44]

Median filtering can be detected on the basis of streaking artifacts or blotching effect. The streaking artifacts represent a forensic probabilistic feature that contains the frequency

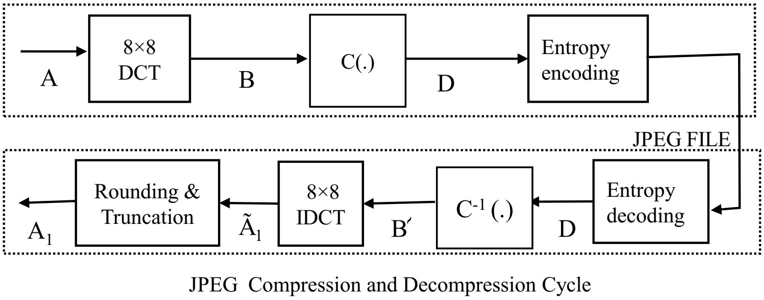
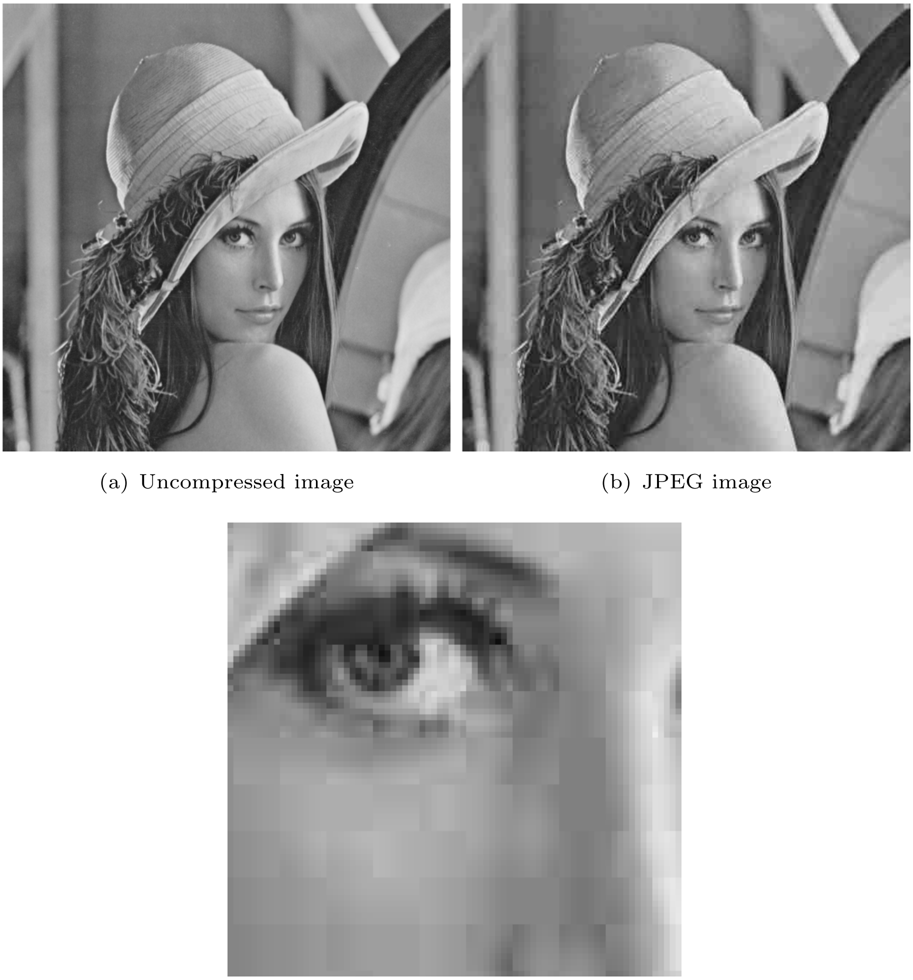


Fig. 4 Block diagram of JPEG compression and decompression cycle



(a) Uncompressed image

(b) JPEG image

(c) zoomed-in view of JPEG image

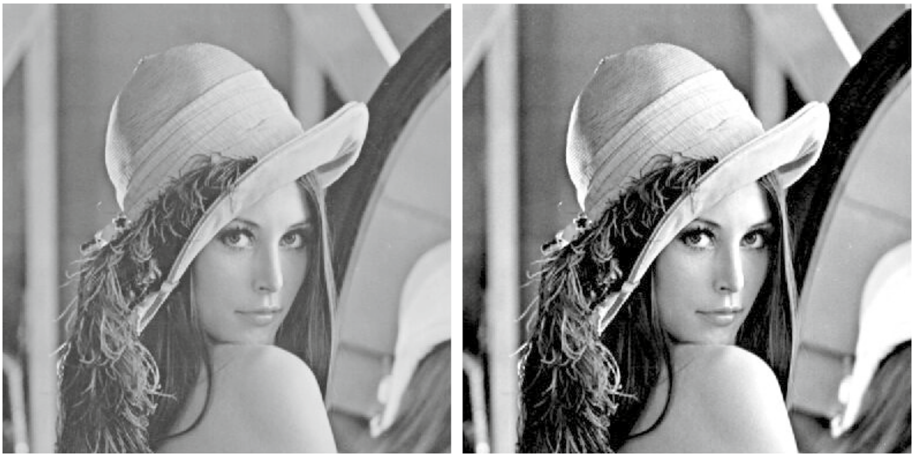
Fig. 5 Example of JPEG blocking artifacts

occurrence of 0 and 1 bins on the histogram of first-order pixel value difference. The value of this probabilistic feature comes out to be around 1 for original images and greater than 1 for median filtered images.

To assess the capability of the forensic detectors, there arises a requirement for anti-forensic techniques. In practical terms, a fabricator tries to escape forensic detection by applying various anti-forensic techniques such as JPEG anti-forensics, Contrast enhancement anti-forensics and Median filtering anti-forensics, etc.

1.3 Anti-forensics

It refers to concealing the traces of different image processing operations which are exploited by a forensic analyst for forgery detection. It is mainly introduced to fool the



(a) Uncompressed image

(b) CE image

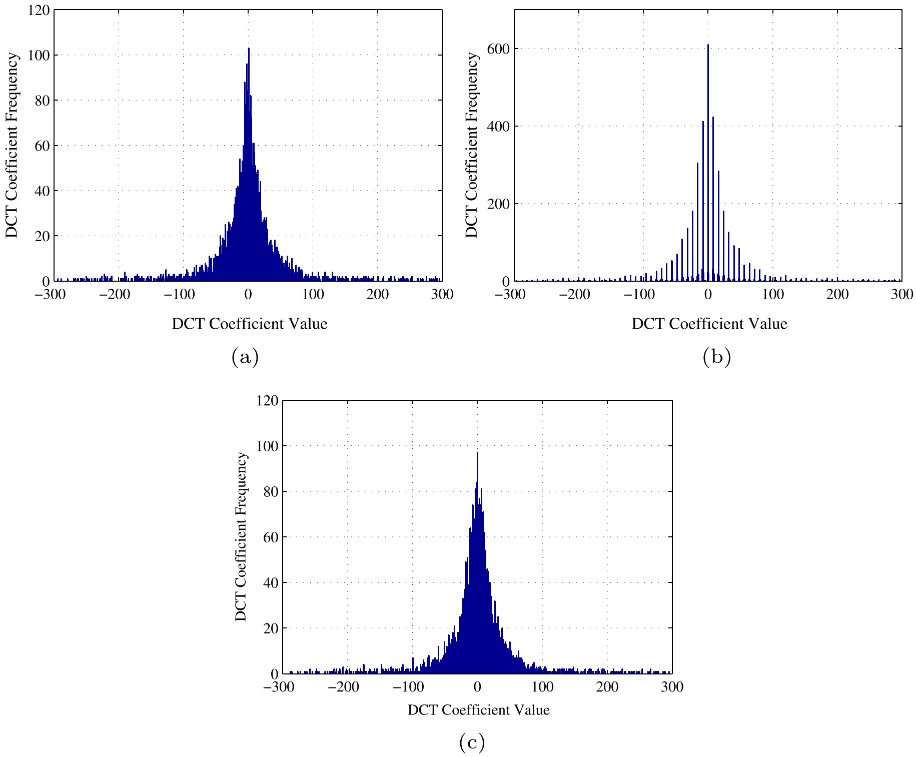
Fig. 6 Example of Contrast enhancement

existing forensic detectors. Forgery is created by applying various image operations, like resizing, rotation, etc., on the copied region before pasting it to the target location in the image. It is of prime importance because the forged images are generally saved in JPEG format, and most of the forgery detection techniques exploit the JPEG compression artifacts.

The main goal of JPEG anti-forensics is to remove the different artifacts of JPEG compression to make the compressed image look like it has never been compressed. Therefore, the forensic analyst needs to develop an efficient and powerful detector that is robust to anti-forensic attacks.

This is illustrated in Fig. 7 with the help of DCT histogram of a particular subband for an uncompressed image, JPEG image, and the image obtained after applying JPEG anti-forensic operation [54]. For this, the genuine uncompressed image is first JPEG compressed with a quality factor of 60, and then the anti-forensic operation [54] is applied to the resulting image. Further, the 5^{th} AC subband (zig-zag order) is considered for plotting the DCT histograms where the quantization step size is 8. It can be observed that a comb-like structure is obtained from the histogram of the JPEG image, and the histogram bins are centered at multiples of quantization step size 8. It is very hard to distinguish between the uncompressed image and the image obtained after applying JPEG anti-forensics as the histograms of the uncompressed image and the image obtained after applying JPEG anti-forensic operation look quite similar. Table 1 shows the true positive rate (TPR) values for different blocking artifact detectors [5, 17, 18] in the presence of JPEG anti-forensic operations [19, 54]. The false positive rate (FPR) is fixed at 0.1 for threshold calculation. It can be deduced from the table that TPR values generally decrease with an increase in quality factor. Further blocking artifact detector [5] is the only effective detector in the presence of anti-forensic operations.

Contrast enhancement anti-forensics is illustrated in Fig. 8 by considering the histograms of an original never enhanced image, normal CE image, and contrast-enhanced image obtained using anti-forensic operation [23]. For this, gamma correction is applied to the given image to get a normal contrast-enhanced image. Further, the anti-forensic operation [23] is applied to get an anti-forensically contrast-enhanced (ACE) image. The gamma



(a)

(b)

(c)

Fig. 7 DCT histograms of (**a**) uncompressed image. (**b**) JPEG image. (**c**) image after applying JPEG anti-forensic operation

value is taken as 0.6 in both cases. The peak and gap artifacts can be clearly observed in the histogram of a normal contrast-enhanced image which is obtained using gamma correction. In contrast, the histogram of the anti-forensically contrast-enhanced image appears to be similar to that of the original never enhanced image.

Table 1 TPR values for various blocking artifacts detectors

Anti-forensic method [54]			
Quality Factor	K_Z [17]	K_W^{λ} [18]	B [5]
40	0.09	0.88	0.97
50	0.04	0.72	0.90
60	0.02	0.48	0.77
70	0.02	0.22	0.51
80	0.02	0.08	0.22
	Anti-forensic method [19]		
Quality Factor	K_Z [17]	K_W^{λ} [18]	B [5]
40	0.10	0.09	0.99
50	0.08	0.13	0.99
60	0.08	0.14	0.99
70	0.07	0.13	0.99
80	0.08	0.13	0.99

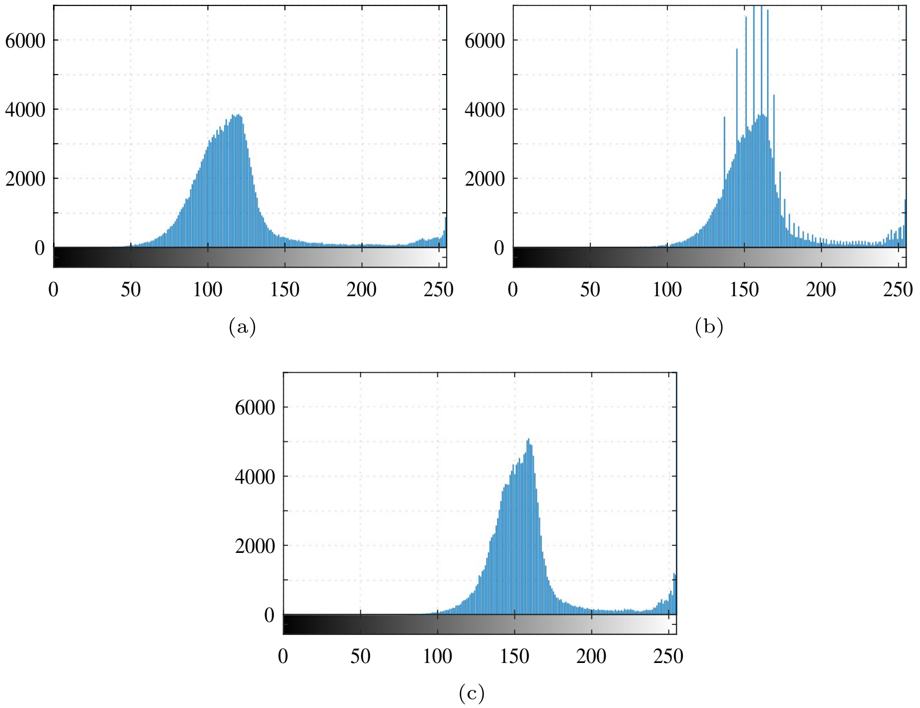


Fig. 8 Spatial domain histograms of (**a**) Original image. (**b**) normal CE image. (**c**) anti-forensically contrast-enhanced image

Median filtering anti-forensics explores the statistical modifications based on the histograms of pixel value difference. The probability of zero values in the first-order pixel value difference map increases with the application of median filtering. Anti-forensics of median filtering is proposed to fool the forensic analyst by abolishing the median filtering artifacts left by statistical changes in edge regions, blurring, etc.

A complete outlook of digital image forensic and anti-forensic scenario is depicted in Fig. 9:

2 Literature review

This section presents a detailed overview of the image anti-forensics methods proposed in the literature. For better understanding, the summary of current state-of-the-art methods is also presented in tabular form.

2.1 JPEG anti-forensics

The literature contains a number of research papers on JPEG anti-forensics. In a pioneering work, an anti-forensic method [55] based on JPEG was proposed by Stamm et al. The method focuses on removing the quantization artifacts of JPEG images by

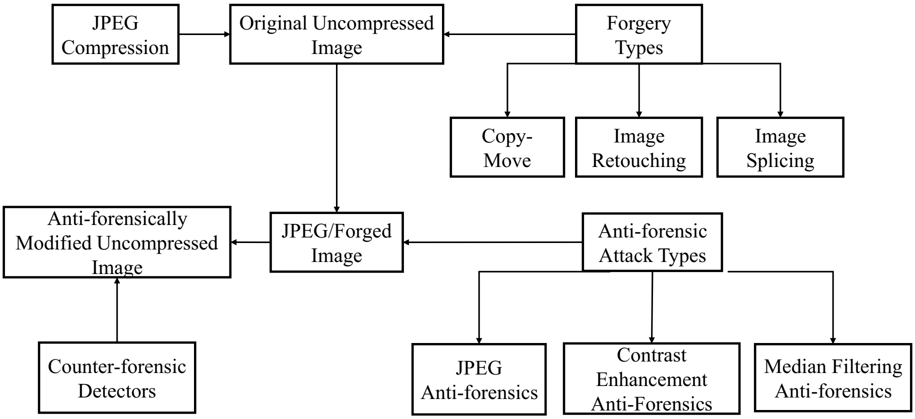

JPEG Compression
Original Uncompressed Image
Forgery Types
Copy-Move
Image Retouching
Image Splicing
Anti-forensically Modified Uncompressed Image
JPEG/Forged Image
Anti-forensic Attack Types
Counter-forensic Detectors
JPEG Anti-forensics
Contrast Enhancement Anti-Forensics
Median Filtering Anti-forensics

Fig. 9 A generalized outlook of digital image forensics scenario

adding an anti-forensic dither. Later on, a deblocking step was incorporated to eradicate the blocking artifacts [54]. The DCT coefficients in distinct AC sub-bands are assumed to be Laplacian distributed, and maximum likelihood estimation (MLE) was used for the estimation of the Laplacian parameter. For the removal of the quantization artifacts, a special noise called anti-forensic dither is added to the quantized DCT coefficients. For the removal of the blocking artifacts, a median filtering operation is applied and then finally, Gaussian noise is added. The deviation of the Gaussian noise depends on the considered JPEG image's quality factor. This technique is shown to be effective in disguising current forensic JPEG detectors.

For deceiving detectors based on double JPEG compression, an anti-forensic method [57] based on Shrink and Zoom (SAZ) was introduced by Sutthiwan et al. The basic idea behind this technique is to preserve the good quality of the image by destroying the JPEG grid structure. For a given double-compressed JPEG image, the technique first decompresses it to the spatial domain, and SAZ operation is then applied using bilinear interpolation. Lastly, the resultant JPEG image is compressed with the secondary quality factor. A universal anti-forensic technique was proposed by Barni et al. [3], which is competent for fooling multiple-JPEG compression detectors based on first-order statistics. This method involves the revision of DCT subband histograms of multiple-compressed images in such a way that the resulting histograms coincide with those of single-compressed images.

In [18], Fan et al. introduced a total variation-based technique to remove blocking artifacts from a JPEG compressed image which helps in defeating different JPEG forensic detectors. Further, it has been shown that the calibration-based detector can be defeated by feature value optimization. A JPEG-based anti-forensic algorithm was proposed by Fan et al. [19] with the objective of refining the conceptual quality of the anti-forensically modified image while maintaining forensic undetectability. The algorithm involves four main steps: deblocking based on first-round total variation (TV), adding conceptual dither in the DCT domain, deblocking based on second-round TV, and lastly, the decalibration.

An enhanced JPEG-based anti-forensic approach for removing the blocking artifacts was highlighted in [51]. These artifacts were left through JPEG compression in both the spatial and DCT domains. The grainy noise obtained by conceptual DCT histogram smoothing was reduced by the introduced denoising operations. Two kinds of denoising operations were used: one with a forced minimization problem of the total change of energy and a second with an adjusted weighted function. Also, for removing the blocking artifacts in the spatial domain, an enhanced TV-based deblocking was used.

The detectors based on the FSD distribution of the DCT coefficients were targeted in the method proposed in [43]. This method is shown to be effective in restoring the FSD distribution of either a single/double compressed image to that of the uncompressed image or a double compressed image to that of a single compressed image.

In [4], Barni et al. provide an overview of adversarial multimedia forensics. The authors first review the techniques proposed by a forensic analyst and a forger (attacker) independently. An attacker may create a forgery which can further introduce some other artifacts in the forged image. A forensic analyst may exploit these artifacts to locate and detect the modified regions in a given image. An attacker may further try to create a realistic image forgery along with the suppression of artifacts and thus results in a thief-and-police game between the fabricator and the forensic expert.

A novel anti-forensic technique was introduced by [30] to check the performance of existing JPEG forensic detectors. The technique comprises two main steps: Firstly, the block-shifted DCT approach is used on the input image, which is JPEG compressed to load the deviations in the arrangement of DCT coefficients. This leads to the addition of dithering noise in the image and a reduction of cost in creating forgery on those images. Secondly, the outcome of block shifted DCT approach is further modified by using deblocking function based on TV to eradicate the leftover JPEG-blocking artifacts.

An efficient method for JPEG anti-forensics based on CNN [1] was proposed for deceiving both JPEG and DJPEG detectors with higher-quality images so as to enhance the performance of existing anti-forensics methods. It was also demonstrated that JPEG and DJPEG detectors could be deceived by JPEG detection in the presence of current anti-forensics but fail to work well in non-aligned cases, resulting in images with lower quality.

The introduction of anti-forensic techniques prompted research on the methods for countering anti-forensics. The methods proposed by Lai et al. [34] and Valenzise et al. [58] are used for countering the anti-forensic technique proposed by Stamm et al. [55]. Two discrete detectors for anti-forensically modified images are proposed in [34]. The first detector makes use of the fact that the high-frequency DCT subbands are not altered by the anti-forensic operation. The second detector utilizes the divergence between the deviation in DCT coefficients of a given image and that of its calibrated version. Valenzise et al. have introduced grainy noise in the spatial domain by the addition of anti-forensic dither in the DCT domain. A technique was proposed for the detection of this anti-forensic operation by using TV to measure the noisiness in a given image.

In [36], Haodong Li et al. introduced a technique based on machine learning for the detection of anti-forensically modified images. The authors observed that the dithering operation destroys the intra and inter-block correlation of an image. From the above surveillance, Markov random processes and transition probability matrices were used for the extraction of a 100-dimensional feature vector. For the training and classification of original, JPEG, and anti-forensically modified images, the SVM classifier is used. In [37], Haodong Li et al. presented a technique based on the residual domain for the detection and classification of various image processing operations as well as anti-forensic operations. The image residual is obtained by performing a high-pass filtering operation to crush the consequence of image details. The authors used spatial rich model (SRM) features [21] with reduced dimensionality for the training of a multi-class SVM classifier.

The experimental results indicate an effective performance of the detector as the method outperforms when working with images tacted with JPEG-aligned and non-aligned anti-forensic techniques.

A Convolutional Neural Network (CNN) based approach [22] was proposed for the classification of multiple JPEG compressed images. Based on DCT histograms of luminance and chrominance color planes, significant features were extracted. A single feature vector was created by concatenating each histogram consisting of 21 low-frequency DCT subbands placed in zig-zag scanning order. The above-generated feature vector can be used for the training of CNN to classify multiple-JPEG compressed images. A forensic technique to counter JPEG anti-forensic attacks was proposed by [52] for analyzing the second-order statistics based on Co-occurrence Matrices (CMs). Three main steps were involved in the proposed method: Initially, a target difference image is selected, then CMs are evaluated, and finally, statistical analysis for second-order is generated based on CMs. Also, this method particularly targets anti-forensic JPEG dithering as compared to other existing techniques. Thus, this method will barely generate false positives.

A novel and robust technique was proposed by [32] for the detection of JPEG compressed images saved in uncompressed format. The detector mainly uses the distinct values in the arrangement of DCT coefficients in the AC subbands of the original uncompressed images and JPEG-U images. Based on the computed difference, a statistic is obtained, which is then used to compare with a threshold for the identification of JPEG-U images. A method for countering the JPEG anti-forensic attacks was presented by [31]. The capability of the detector depends on the identification of JPEG anti-forensics. The proposed technique involves three main steps: Firstly, a target difference image is picked out, secondly, for inter and intra-block computations, Markov Transition Probability Matrices (MTPMs) are evaluated in the DCT domain, and second-order statistical features are generated based on the evaluated MTPMs, lastly, for training and classification of resultant features, SVM classifier is used. From the experimental results, it can be observed that the proposed forensic technique outperforms other existing techniques in terms of minimum decision error, whose small values will indicate better detection.

2.2 Contrast enhancement anti-forensics

Various forensic methods for the detection of contrast enhancement were proposed, and these methods rely on checking image histograms for the presence of peaks and gaps. A novel forensic method was proposed for exposing cut-and-paste image forgery [38] through the detection of contrast enhancement. This involves revealing the inter-channel correlation introduced by interpolated images and showing how a linear or non-linear contrast enhancement can change this natural inter-channel correlation. To measure this inter-channel correlation, a metric was used, which also helps in differentiating the original image from a CE image.

Further, two methods were introduced by [39] for the detection of contrast enhancement. The first method uses a quadratic weighing function to measure the distortion in the image histogram resulting from the presence of contrast enhancement. While the second method uses the strategy of linear threshold to get along with the selection of the threshold. Both methods result in the effectiveness of the performance in terms of ROC curves.

Contrast enhancement creates a realistic composite image by adjusting the brightness and contrast of the image. Therefore there is a need to identify contrast enhancement in images so as to check the authenticity of digital images. Two novel techniques were introduced for the identification of contrast enhancement-related manipulation [8]. The first method focuses on analyzing peak/gap artifacts in the histogram introduced by JPEG compression and pixel value mappings for the identification of global contrast enhancement and distinguished by identifying the zero-height gap fingerprints. In the second algorithm, the clustering of block-wise peak/gap bins was done to recognize the contrast enhancement mappings applied to digital images.

Thereafter anti-forensic methods were introduced based on peak-gap artifacts [6] of the pixel gray level histogram. After that, an alternative method [33] was proposed, which tries to remove these peaks and gaps by applying random dither, thereby impacting the accuracy of the contrast enhancement detection method and, at the same time, maintaining good image quality. An anti-forensic technique based on contrast enhancement [23] was proposed, which results in similar characteristics as that of the original unenhanced image and lower TV. This is realized by having negligible distortion in the first and second-order statistics of the processed image and thus can easily fool the existing contrast enhancement detectors.

A novel counter-forensic contrast enhancement technique was proposed to suppress the captured artifacts [2] in the process of contrast enhancement operation. The method generates a CE image by using the information in both spatial and DCT domains. It shows robustness against various contrast enhancement detectors and effectiveness in terms of image quality metrics.

Contrast enhancement anti-forensic methods are good at removing forensic footprints from the histogram of the CE image by showing their forging capability, but at the same time, they ignore the problem of exposing changes in pixel values in the pixel domain. This problem was solved by an anti-forensic contrast enhancement method [70] based on Generative Adversarial Network (GAN). GAN is used for the processing of CE images in the pixel domain and making it difficult to differentiate them from the original image. A histogram-based loss is used to increase the efficiency of the attacks in both the histogram domain and the Gray Level Co-occurrence Matrix (GLCM) domain. The method shows better anti-forensic attack performance with improved image quality.

Usually, first-order statistics obtained from histograms were used for the detection of contrast enhancement in digital forensic analysis, but methods using this scheme somewhat perform badly in the company of various counter-forensic attacks, therefore a novel forensic second-order statistics-based technique [16] obtained through CM was presented.

An iterative algorithm for estimating contrast enhancement was introduced by [60] to expose forgeries in digital image. The method recovers the differences in the original image pixel histogram and contrast enhancement image pixel histogram so as to identify composite images. It works quite effectively in the presence of dithering noise, which can be used for locking up the footprints of contrast enhancement. A novel forensic technique for contrast enhancement based on CNN was proposed by [56]. In this method, CNN appropriately detects modifications and extracts suitable features by learning representations of hierarchical features and optimizing the results of classification. Also, CNN is fed with a GLCM, which makes it superior in terms of detecting forgeries in the company of various counter-forensic attacks.

The above-proposed methods for contrast enhancement were not effective in the presence of some image processing operations, so contrast enhancement forensics was analyzed in the pixel domain and histogram domain. Two robust methods based on CNN [65] were introduced for the detection of contrast enhancement in the presence of JPEG compression and various anti-forensic attacks. Further, a modified CNN-based JPEG robust method [48] was presented for the detection of contrast enhancement. The modified CNN accepts enhanced images as inputs and outputs the GLCM, which contains contrast enhancement fingerprints.

Further, the above problem was solved by introducing a new deep learning structure based on a dual-domain fusion CNN [63], which shows robustness against various contrast enhancement levels, anti-forensic attacks, and pre-JPEG compression. Contrast enhancement forensics was performed by fusing the features of the pixel domain and histogram domain. P-CNN was used to capture the pixel domain patterns, while H-CNN was responsible for the extraction of the significant features in the histogram domain. The fully connected layers of CNN were fed with the fused feature patterns of both domains for classification purposes.

2.3 Median filtering anti-forensics

A forensic environment in the digital era requires the establishment of efficient methods for tracing out the significant modifications that occurred because of the presence of median filtering. Median filtering causes the removal of forensic artifacts. A passive method [7] was proposed for spotting the presence of median filtering, which mainly involves analyzing statistical characteristics and measuring the probability of zero values on the difference map. Further, another passive method [9] was introduced based on the view that the images undergone median filtering involve distinct footprints around edges such as preservation of edges, suppression of noise, correlation of neighboring pixels, etc. Based on these median filtering traces, an edge-based prediction matrix (EBPM) is formed that carries approximate projection coefficient values among edges, and finally, the SVM classifier is used for classification. The above method was further improved by detecting median filtering in arbitrary images, even those images which contain very less resolution [66] and are compressed using JPEG compression.

The method in [9] was improvised by introducing another statistical technique [10] that uses statistical features in the different domains of images. In this technique, the cumulative distribution function of first-order differences was derived, and the behavior of adjacent difference pairs was analyzed in the difference domain for original images, median filtered images, etc. There is an improvement in the method presented in [66] as now a novel forensic trace called Median Filter Residual(MFR) was introduced for the identification of median filtering from an image compressed using JPEG compression. It reduces the image edge and texture interference, which was the major limitation of the previous method. A vigorous technique for the detection of median filtering was proposed for analyzing the statistical characteristics of MFR. An autoregressive (AR) model [26] was used for gathering the statistical characteristics of MFR, and AR coefficients are considered as features that are used for the training of SVM for the identification of median filtering. The method works effectively for JPEG-compressed images with lower quality factors and shows increased performance in the presence of low false-positive rates.

Another improvement in the above median filtering detection methods had been made using an approach based on difference domain where two new feature sets [11] were introduced for differentiating an original uncompressed image from an image that had undergone median filtering or an image possessing average median filtering. This method shows robustness in the presence of noise and efficacy in the case of less resolution and more JPEG post-compression. Another novel method [68] was proposed for the identification of median filtering, which requires the use of a local texture operator called local ternary pattern (LTP). The variations in the local texture were encoded by a suitable coding function, and the changes caused by median filtering in the local texture were effectively captured by LTP. The method was cost-effective by using kernel principal component analysis (KPCA) so as to reduce the feature set's dimensionality.

After that, a deep learning-based method [12] for median filtering detection was proposed in which a CNN impulsively learns the hierarchical traits and performs classification. The method was efficient for small and JPEG-compressed image blocks and best suited for the identification of cut-and-paste forgeries. A frequency-domain feature-based method [40] was introduced for distinguishing median filtered images from original, gaussian low pass filtered, and average filtered ones, significantly in case of less resolution and images compressed using JPEG compression. The technique shows reliability by reducing the computational time required for classification, thereby depicting the applicability in the real-time operation of massive interactive media.

There is improvement proposed in the method [26] for the detection of median filtering in heavily compressed images by using a two-dimensional auto-regressive model (2D-AR) for capturing the statistical characteristics of MFR, average filtered residual (AFR), and gaussian filtered residual (GFR) respectively, and combining the 2D-autoregressive coefficients [64] of the three residuals so as to obtain a feature set. The derived feature set is fed to the SVM for training and classification. An improved approach for the identification of median filtering in heavily compressed and low-resolution images was introduced for the construction of a feature set based on the residuals by including the Markov chain with the AR model [44]. These models help in revealing dissimilar correlations among neighboring residuals, and various methods to reduce dimensionality are hired for fast detection. Anti-forensics are applied to fool the existing forensic detection of median filtering. One such anti-forensic technique [61] was introduced by adding noise to the pixel difference distribution of images. Both the original image and the median filtered image's pixel difference distribution were estimated, and when noise distribution was added, the pixel difference arrangement of an anti-forensically modified image seemed to surface from the original uncompressed image. To limit distortion that arises in the process of modification, several measures were employed.

A novel anti-forensic method [14] was proposed to hide the traces of median filtering by using the information of features via suitable random pixel modification. The method shows efficacy in terms of improvement in image quality.

Further, a variational deconvolution framework [20] was proposed for quality improvement and anti-forensics of the median filtered image, which consists of convolution term, fidelity term, and prior term. The estimation of the median filtering operation was done by a convolution kernel. The fidelity term keeps some image processing footprints and denoising hiding effects in processed images close to the image, which is median filtered. Finally, the prior term reconciles the pixel value outcomes of the altered image to coincide with the distribution of the original image.

An efficient anti-forensic technique [50] was proposed to hide the traces of median filtering operation by ensuring a minor change in spatial characteristics. The method uses statistics of the image as a difference between Anistrophic and Isotrophic TV regularization. Another median filtering anti-forensic method [29] based on CNN was introduced to eradicate the traces from median-filtered images. The GAN framework was used for the generation of images that obey the key statistical properties of the original unaltered image, thus improving forensic undetectability.

Now a two-step median filtering anti-forensics framework was introduced [53], which hides the median filtering traces to fool the median filtering detectors. The framework involves the generation of median-filtered forgery using a variational deconvolution approach. After that, the remains of median filtering left during the deconvolution process was removed by using TV based minimization algorithm. The method shows effectiveness on the basis of obtaining a better quality image and achieving good forensic undetectability. An improved technique better than the above methods was introduced to hide the traces of median filtering anti-forensics [25], thereby reducing forensic detectability. The blurred edges in the output of median filtering were restored by Unsharp Masking(UM). The peak signal-to-noise ratio (PSNR) between the initial loaded image and the refined output image was used as the minimum error sense criterion for the evaluation of the optimum amount, which controls the degree of sharpening. The values of PSNR seem to be higher in this approach as compared to previous anti-forensic techniques such as CNN, VD, and VD with TV minimization.

For countering median filtering anti-forensics, a novel technique [67] was introduced to analyze the fingerprints left by median filtering anti-forensics at a computationally low cost. Further, an improved counter anti-forensic technique [27] was presented for the detection of anti-forensic attacks proposed in [67]. The technique works by adding noise adaptively in the pixel domain based on a constant signal-to-noise ratio (SNR). For better understanding, the current state-of-the-art anti-forensic detection methods are summarized in Table 2:

3 Conclusion and future scope

This paper presents a detailed review of various anti-forensic techniques used in digital image forensics. It has been shown that a forger can use various anti-forensic operations to hide the evidence of image manipulation, which can lead to false decisions in a court of law. So it is the need of the hour to stop these forgers and their wrong intentions. The main emphasis of the survey is on JPEG anti-forensics, Contrast enhancement anti-forensics, and Median filtering anti-forensics. JPEG anti-forensics involve various techniques which are capable of removing quantization and blocking artifacts and resulting in an anti-forensically modified uncompressed image that looks similar to the original uncompressed image. So it becomes difficult for forensic experts to distinguish authentic uncompressed images and the anti-forensically modified uncompressed image. The median filtering and contrast enhancement operations play an important role in forensic analysis. The methods for contrast enhancement and median filtering anti-forensics are elaborated along with the JPEG anti-forensics. Currently, most of the existing forensic detectors either get fooled by the various anti-forensic attacks or do not account for the possibility of anti-forensics. The presented survey may be utilized by a forensic expert to design robust techniques that will be able to handle the above-mentioned problems and achieves better accuracy. Further, forensic experts can take ideas from the presented study to combine two existing techniques to detect different anti-forensic operations. It is possible that these techniques may not perform well if applied individually as compared to when they are combined together. The limitation of the presented study is that it does not include the various aspects of video forensics/anti-forensics, which will be included in future work.

Table 2 Current state-of-the-art anti-forensic methods

Reference	Category	Research Findings
Stamm et al.(2010) [55]	JPEG anti-forensics.	● Removal of quantization artifacts by adding anti-forensic dither. ● Distribution of anti-forensically modified coefficients matches an estimate of the distribution of unquantized DCT coefficients.
Stamm. and Liu.(2011) [54]	JPEG anti-forensics.	● Removal of blocking artifacts by incorporating a deblocking step. ● Removal of quantization artifacts by estimating image's transform coefficient distribution before compression and after adding anti-forensic dither.
Sutthiwan and Shi.(2012) [57]	JPEG anti-forensics.	● Preserves good quality image by destroying JPEG grid structure. ● Modifies image by JPEG deblocking, shrinking and zooming image with bilinear interpolation before performing JPEG compression.
Fan et al.(2013) [18]	JPEG anti-forensics.	● Formulize the anti-forensic JPEG deblocking as a total variation based variational image restoration problem. ● Defeats calibration based detectors by applying feature value optimization after deblocking.
Fan et al.(2014) [19]	JPEG anti-forensics.	● Improves previous JPEG anti-forensics work by integrating a step of explicit smoothing of DCT histogram. ● Shows effectiveness in terms of perceptual quality and forensic undetecta bility.
Singh and Singh (2017) [51]	JPEG anti-forensics.	● Introduction of denoising operations for reducing the grainy noise obtained by DCT histogram smoothing. ● Use of enhanced TV based deblocking for the removal of blocking artifacts.
Kumar et al. (2019) [30]	JPEG anti-forensics.	● Use of block shifted DCT to load deviations in DCT coefficient distribution. ● Use of deblocking TV based function to remove JPEG blocking artifacts.
Kim et al. (2021) [1]	JPEG anti-forensics.	● Both JPEG and DJPEG detectors can be decieved. ● Fails to work well in non-aligned cases and results in lower quality image.
Lai and Bohme (2011) [34]	Countering JPEG anti-forensics.	● High frequency DCT sub bands are not altered by anti-forensic operation. ● Use of divergence between the deviation in DCT coefficients of image and its calibrated one.
Valenzise et al.(2013) [58]	Countering JPEG anti-forensics.	● Introduction of grainy noise in spatial domain by adding dither in DCT domain. ● Use of TV for measuring noisiness in image.
Li et al.(2012) [36]	Countering JPEG anti-forensics.	● Dithering destroys intra and inter-block correlation of an image. ● Use of markov random processes and transition probability matrices for extraction of feature set.

Table 2 (continued)

Reference	Category	Research Findings
Bhardwaj and Pankajakshan (2018) [5]	Countering JPEG anti-forensics.	• Detection of blocking artifacts based on the correlation among the blocks of DCT coefficients. • Shows effectiveness when working with images tacted with aligned and non-aligned anti-forensic techniques.
Singh and Singh (2019) [52]	Countering JPEG anti-forensics.	• Detection of Anti-forensically modified images in the presence of median filtering and contrast enhancement. • Selection of target difference image. Use of SVM classifier. • Does not work in the presence of Re sampling anti-forensics.
Kumawat and Pankajakshan(2020) [32]	Countering JPEG anti-forensics.	• Detection of JPEG Compression in JPEG-U images. • Works well in detecting post-processed and anti-forensically modified JPEG-U images. • Fails to classify anti-forensically modified SAF2 images.
Kumar et al. (2021) [31]	Countering JPEG anti-forensics.	• Detection of JPEG Compression • Reduced values of Minimum decision error(MDE). • Achieve better forensic detectability. • Does not work well in the presence of other anti-forensic techniques.
Kwok et al.(2011) [33]	Contrast enhancement anti-forensics.	• Shows efficiency against first and second order statistics based CE detectors. • Shows no degradation in image quality.
Ravi et al. (2016) [23]	Contrast enhancement anti-forensics.	• Alternative method to avoid peak-gap artifacts. • Shows good image quality in terms of PSNR.
Mehrish et al. (2019) [2]	Contrast enhancement anti-forensics.	• Use of information in spatial and DCT domains for the generation of CE images. • Shows robustness against CE detectors and efficiency in terms of image quality assessment metrics.
Zou et al. (2021) [70]	Contrast enhancement anti-forensics.	• Use of histogram based loss to increase the efficiency of attacks. • Shows better anti-forensic attack performance with improved image quality.
Rosa et al. (2015) [16]	Countering contrast enhancement anti-forensics.	• Use of second order statistics for finding traces of histogram processing. • Shows effectiveness in the presence of counter forensic attacks.
Sun et al.(2018) [56]	Countering contrast enhancement anti-forensics.	• Detection and extraction of suitable features by learning representations of hierarchical features and optimizing the results of classification. • CNN is fed with gray level co-occurrence matrix which makes it superior in detecting forgeries in the presence of counter forensic attacks.

Table 2 (continued)

Reference	Category	Research Findings
Yang et al.(2019) [65]	Countering contrast enhancement anti-forensics.	● Detection of contrast enhancement in the presence of JPEG compression and various anti-forensic attacks. ● Analysis of CE in pixel and histogram domains.
Shan et al.(2019) [48]	Countering contrast enhancement anti-forensics.	● Modified CNN accepts enhanced images as input and generates GLCM as output. ● Detects local and global CE by the use of cropping layer to reduce noise in GLCM. ● Detects contrast enhancement in images which are JPEG compressed and then contrast enhanced or images which are contrast enhanced and then JPEG compressed.
Yang et al. (2021) [63]	Countering contrast enhancement anti-forensics.	● The features of pixel and histogram domains are fused for performing contrast enhancement forensics ● P-CNN was used to capture the pixel domain patterns. ● H-CNN was used to extract the significant features in the histogram domain.
Fan et al. (2015) [20]	Median filtering anti-forensics.	● Use of convolution, fidelity and prior terms for anti-forensics. ● Improved image quality.
Sharma et al. (2016) [50]	Median filtering anti-forensics.	● Use of image statistics as a difference of Anistrophic and Isotrophic TV regularization. ● Ensures minimal change in spatial characteristics.
Kim et al. (2018) [29]	Median filtering anti-forensics.	● Use of GAN framework for the generation of images that follow the statistical traces of unaltered image. ● Improves forensic undetectability.
Singh et al. (2019) [53]	Median filtering anti-forensics.	● Use of TV based minimization algorithm. ● Improved image quality with good forensic undetectability.
Kaimal et al. (2019) [25]	Median filtering anti-forensics.	● Use of PSNR values for the evaluation of degree of sharpening. ● Improved forensic undetectability.
Zeng et al. (2014) [67]	Countering Median filtering anti-forensics.	● Analyze the traces of median filtering anti-forensics at low computational cost. ● Detects anti-forensic forgery with low complexity and improves forensic security.
Kang et al. (2015) [27]	Countering Median filtering anti-forensics.	● Addition of noise in the pixel domain based on constant SNR. ● Improved detection of anti-forensic attacks.
Li et al. (2018) [37]	Countering JPEG anti-forensics, Contrast enhancement anti-forensics and Median filtering anti-forensics.	● Use of high pass filtering operation to obtain image residual for removing the traces of various anti-forensics. ● Use of SRM for the training of SVM.

Declarations

The authors declare that they do not have any personal or financial conflict of interests.

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