Content-Based Watermarking by Geometric Warping and Feature-Based Image Segmentation

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Abstract. In this work, we present a new content-based watermarking approach that uses geometric warping to embed watermarks with high robustness to strong lossy compression. The issue of hard decisions related to content-based watermarking is discussed and it is explained why hard decisions can involve bit errors in the watermark extraction process. This work contains a solution to prevent hard decisions increasing the watermark performance. Therefore, we introduce a new feature-based image segmentation process with high robustness to lossy compression. On the basis of the segmentation, a watermark approach is proposed. Further, a secret key can be used to prevent unauthorized access to the watermark. The watermark extraction process does not need the original image. Our analyses of the watermark approach confirm the expected high robustness to strong lossy compression.

Keywords: Content-Based, Geometric Warping, Watermarking, Data Hiding, Image Segmentation

1 Introduction

Digital data techniques more and more replace analogue data techniques. The advantages are obviously. Digital data can be copied, edited and transferred without high efforts. However, at the same time it is very simple to make illegal copies and to manipulate digital data. Digital watermarking [**1**] offers contributions in protecting the authenticity of the data and the copyrights of the authors.

One property of digital watermarks is the robustness describing the possibility to extract the watermark after permitted or malicious modification of the digital data. There are watermark methods that achieve robustness to different attacks such as cropping, rotating, scaling, compression and noise ([**2**] gives an overview). Robustness to many attacks can be important. However, mostly these watermarks are not robust to strong lossy compression or contain only a low amount of information (watermark capacity). High robustness and a suitable capacity can be achieved using content-based watermarking approaches [**3**]. Because compression algorithms try to maintain the content, the watermarks are embedded into it. The challenge of content based watermarking is to find a suitable definition of content and to solve the problem of hard decisions.

In this paper, we present a new content-based watermarking approach basing on geometric warping. Firstly, the basic idea of watermarking by geometric warping is described. Afterwards, the issue of content-based watermarking related to hard decisions is discussed. In the next section, the basic idea of content-based watermarking without hard decisions is explained. Therefore, different types of image features are introduced which are used for a feature-based segmentation and the embedding and extraction process. Finally, the results are presented including analyses of the watermark robustness to strong lossy compression.

2 Geometric Warping Watermarking

Generally, the performance of a watermark is defined by the watermark properties capacity, robustness and visibility. These properties depend on each other. Many watermarking methods achieve a low watermark visibility by changing the gray values of images only slightly. Some of them are SS (Spread Spectrum) [4], LSB (Least Significant Bit) [5] and DCT transformation based Quantisation Index Modulation watermarking approaches [6]. An example of Spread Spectrum watermarking is shown in Fig. 1 a) and b). However, the approaches of changing pixels only slightly to embed the watermark compete with lossy compression algorithms. To achieve robustness to lossy compression the watermark capacity has to be reduced. Hence, it is difficulty to embed a watermark especially with robustness to strong lossy compression and a suitable capacity at the same time.

The basic idea of geometric warping watermarking can be summarized as follows:

- Changing the position of object borders of an image results in high difference values (see Fig. 1 c) and d))
- Compression algorithms try to change gray values only slightly (because they are PSNR-optimized)
- Hence, compression algorithms try to maintain the position of object borders
- To embed the watermark, the position of object borders is changed by warping
- The watermark information is contained in the position of object borders and robust to strong lossy compression

A more detailed explanation can be found in [7]. Other geometric warping based watermarking approaches are given in [8] and [9].

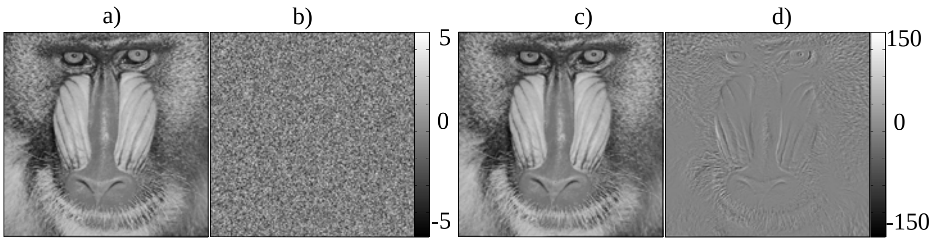

Fig. 1. Image „Mandrill“ with SS watermarking a), corresponding difference image b), warped image “Mandrill” c) and corresponding difference image d).

3 Issue of Hard Decisions

Geometric warping based watermarking is content-based watermarking. The content can be understood as perceptually significant features in the data. The content is changed to embed the watermark with robustness to lossy compression. However, we can't embed a watermark if there is no, for the watermark method, recognizable content. Hence, to embed the watermark we have to decide what and where the content of an image is. For the latter, image segmentation is necessary.

Maes et al. propose in [8] a zero-bit [10] watermarking approach. They take the complete image to embed a watermark without any bit information. Hence, they need no segmentation. In [9], we propose a multi-bit video watermarking approach. The video is divided into two groups of blocks. In blocks which have a suitable content for watermarking and blocks without a suitable content. The watermark bits are embedded only into the suitable blocks. To extract the watermark after strong lossy compression the two groups of blocks have to be reconstructed.

The issue of hard decision in content-based watermarking is to decide whether an image region, for example a block of a block-based watermarking approach, is suitable for watermarking or not. Using this hard decision involves the probability of fail decisions after lossy compression. A fail decision can involve a watermark bit error or completely destroy the watermark.

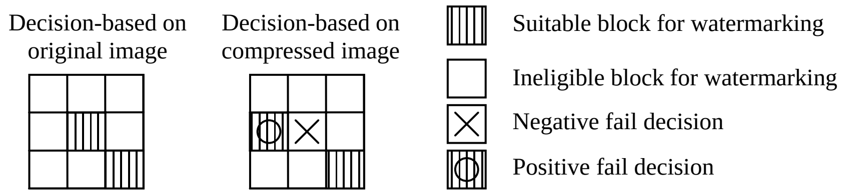

Fig. 2. Principle of failed hard decision.

A possibility to solve the problem of fail decision is to use error correction codes. However, it is only efficient if the number of embedded and of extracted bits are the same. Otherwise, the necessary overhead of the error correction code decreases the watermark capacity a lot.

In [9], we use a pre-distortion of the blocks to prevent fail decisions. A block-feature combined with a threshold $\boldsymbol{t}$ is used to decide whether a block is suitable for watermarking or not. To reduce the probability of fail decisions, blocks with a value of the feature near the threshold are pre-distorted. The process changes the blocks in a way that the new value of the feature has a higher distance to the threshold $\boldsymbol{t}$. After pre-distortion there is a gap in the feature-value distribution.

The problem of hard decision can be solved on several ways. However, every solution has disadvantages. Whereas the use of error correction codes reduces the watermark capacity, creating a gap requires a pre-distortion and increases the watermark visibility. The advantage of a content-based watermarking approach without hard decisions is an increased performance of the watermark. In the following sections, we propose a multi-bit geometric warping based watermarking method without hard decisions.

4 A Geometric Warping Watermark Approach Without Hard Decisions

4.1 Basic Idea

Content-based watermarking uses features which describe the content of an image. For content-based watermarking without hard decision we propose to use two different types of features.

The first feature describes the type of the content (Locator-Feature). For example, the Locator-Feature could describe the strength of the edges inside a block. This feature is used to find content which is suitable for watermarking. The second feature describes the content (Carrier-Feature). For example, the Carrier -Feature could describe the position of the edge inside a block.

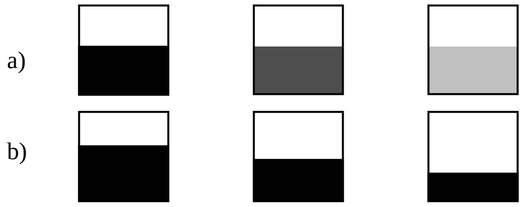

Fig. 3. Example with a) different content type (Locator-Feature - edge strength) and b) different content (Carrier-Feature - edge position)

To embed the watermark, the Locator-Feature is used to find content which has a suitable Carrier-Feature. The embedding process changes the content without changing the type of content. Starting from these assumptions we can create a content-based geometric warping watermarking approach without hard decisions.

We propose to use a Locator-Feature-based segmentation process to get only suitable blocks respectively segments for watermarking. A hard decision is not necessary. The image can be divided into segments even if the content is uniform or non-uniform (see **Fig. 4**). The Carrier-Feature of each segment is used to carry one watermark bit. The segmentation can be reconstructed after strong lossy compression if both features are robust to strong lossy compression.

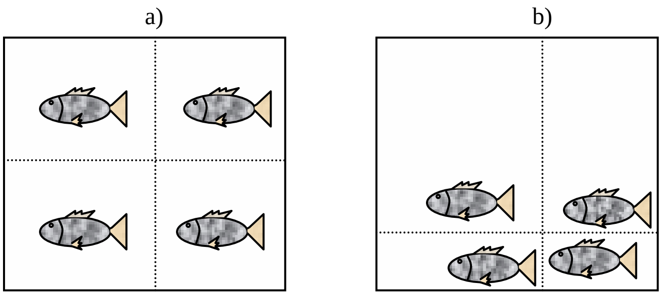

Fig. 4. Simplified principle of Locator-Feature based image segmentation. Each of the four segments contains the same "amount" of content. It doesn't matter if the content is uniform a) or non-uniform b).

4.2 Locator- and Carrier Feature

In [9], we propose the NCG (Normed Centre of Gravity). The NCG is a block-based statistic. It describes the strength and position of the gravity centre of a block in a block border independent way. To compute the NCG of a block with size $\boldsymbol{n} \times \boldsymbol{n}$, the mean values of all columns and rows yielding the vectors $\underline{\boldsymbol{m}}_x$ and $\underline{\boldsymbol{m}}_y$ are used (see **Fig. 5**). Both vectors are used to compute the 2-dimensional vector $\underline{\boldsymbol{v}}_k$ ($\boldsymbol{k}$=$\boldsymbol{x}$ *or* $\boldsymbol{y}$):

$$\underline{\boldsymbol{v}}_k = \left(\begin{array}{c} \sum_{i=1}^{n} \underline{\boldsymbol{m}}_k(\boldsymbol{i}) \cdot \cos\left(\frac{\pi}{n} + \left((\boldsymbol{i}-1) \cdot \left(\frac{2 \cdot \pi}{n} \right) \right) \right) \\ \sum_{i=1}^{n} \underline{\boldsymbol{m}}_k(\boldsymbol{i}) \cdot \sin\left(\frac{\pi}{n} + \left((\boldsymbol{i}-1) \cdot \left(\frac{2 \cdot \pi}{n} \right) \right) \right) \end{array} \right) \quad (1)$$

For both vectors, angles θ_k are computed. These values are used to compute the x,y-coordinates of the NCG:

$$\boldsymbol{x} = \frac{\boldsymbol{n} \cdot \theta_x}{2 \cdot \pi} \qquad \boldsymbol{y} = \frac{\boldsymbol{n} \cdot \theta_y}{2 \cdot \pi} \quad (2)$$

Locator-Feature:
The strength $\boldsymbol{L}$ of the NCG is used as Locator-Feature. It bases on the vector length $\boldsymbol{L_k}$ of $\underline{\boldsymbol{v}}_k$:

$$\boldsymbol{L} = \sqrt{\boldsymbol{L}_x^2 + \boldsymbol{L}_y^2} \quad (3)$$

Carrier-Feature:
The NCG x,y-coordiantes are mapped on a self adapting quantization lattice. The resulting value $\boldsymbol{s}$ is very robust to lossy compression. For a detailed description of this process, see [9]. This value $\boldsymbol{s}$ is used as Carrier-Feature.

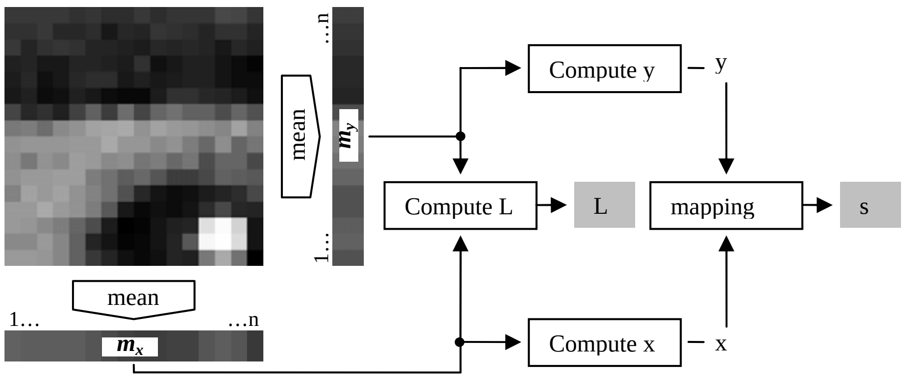

Fig. 5. Overview of the Locator- and Carrier-Feature calculation scheme.

To realize a Locator-Feature based image segmentation, the NCG has to be computed for each pixel. Therefore, the pixels surrounding the current pixels are used to build a block. The NCG of the block represents the NCG of the current pixel.

Each pixel delivers a Locator-Feature and a Carrier-Feature. The results are the Locator-Feature matrix ***LFM*** and the Carrier-Feature matrix ***CFM***. For example, see Fig. 6.

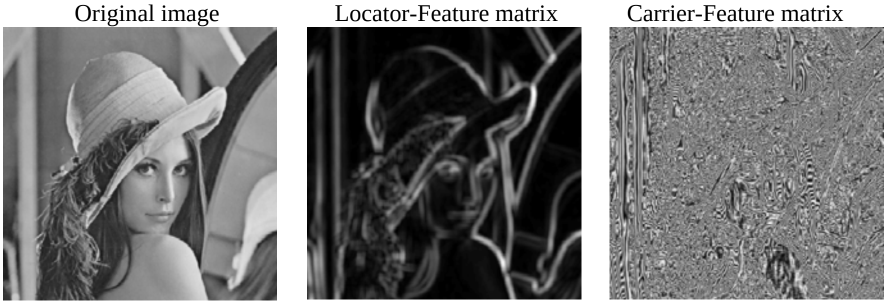

Fig. 6. Example of the NCG Locator- and Carrier-Feature matrices.

4.3 Locator-Feature-Based Image Segmentation

The aim of Locator-Feature-based image segmentation is a uniform qualification of each segment to carry a watermark bit. It is necessary to reconstruct the segments even after strong lossy compression. Hence, the segments respectively the segmentation process has to be robust to strong lossy compression.

A higher value ***L*** (Locator-Feature) yields a higher robustness of the value ***s*** (Carrier-Feature). Hence, one segment needs either many pixels with low values ***L*** or only some pixels with high values ***L*** to carry a watermark bit with the same robustness to lossy compression. Because of this, we propose to divide the image into segments where the sum of the ***LFM*** elements in each segment is the same. Therefore, following algorithm is used:

1. The columns of ***LFM*** are averaged.
2. The resulting vector is divided into ***a*** segments whereby the sum of the vector elements in each segment is equal.
3. Each vector segment represents a set of columns in ***LFM.***
4. Each set of columns is divided into ***b*** segments by averaging the rows and dividing the resulting vector into ***b*** segments whereby the sum of the vector elements in each segment is equal.
5. The results are $\boldsymbol{a} \cdot \boldsymbol{b}$ segments where the sum of the ***LFM*** elements in each segment is the same (see Fig. 7).

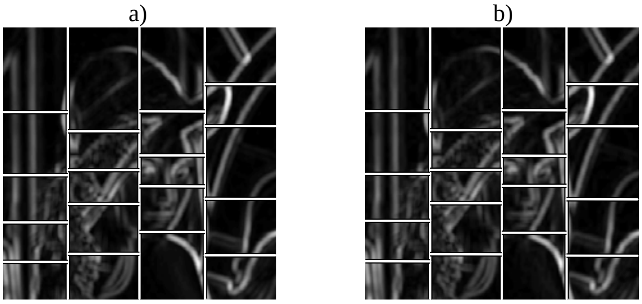

Fig. 7. Example of Locator-Feature-based segmentation with a) segments of original image "Lena" and b) segmentation after strong lossy compression (JPEG with quality factor 15).

The robustness of the segments is analyzed by using JPEG and JPEG2000 (JasPer-Codec). As shown in Fig. 8, the mean error of the segmentation is relatively low also after strong lossy compression. The maximal mean error of about 10% means that 90% of a segment respectively 90% of the location of the Carrier-Feature can be reconstructed.

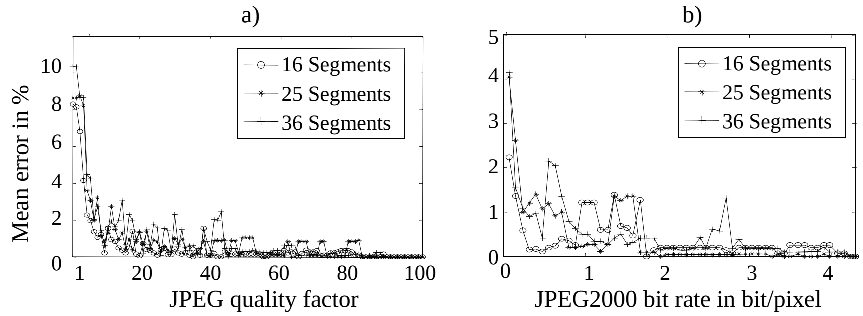

Fig. 8. Robustness of the segments to a) JPEG and b) JPEG2000 compression.

5 Watermark Embedding and Extracting

To embed the watermark bit, matrix ***LFM***, ***CFM*** and a pseudo random binary pattern ***BP*** are used. The binary pattern has the same size as matrices ***LFM*** and ***CFM*** and can be created by a known algorithm or a secret key. Hence, the watermark can be protected against unauthorized access. For example, see Fig. 9. Matrix ***LFM*** is normalized to a value range between 0 and 1 and element wise multiplied with matrix ***CFM*** (Fig. 9 d)).

$$\boldsymbol{LCM} = \boldsymbol{LFM}_{\boldsymbol{normalized}} \cdot \boldsymbol{CFM} \quad (4)$$

The resulting matrix ***LCM*** is very robust to lossy compression. To create a relationship between the elements of matrix ***LCM*** and their spatial positions matrix ***LCM*** is element wise multiplied with matrix ***BP*** (Fig. 9 e)). Result is matrix ***LCBM***.

$$\boldsymbol{LCBM} = \boldsymbol{LCM} \cdot \boldsymbol{BP} \quad (5)$$

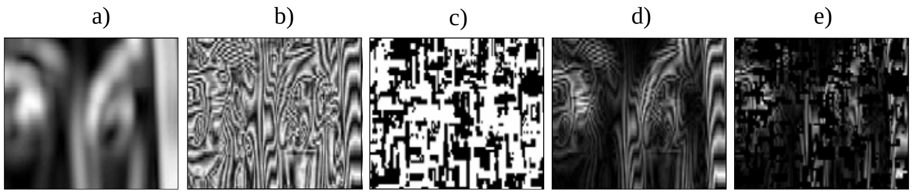

Fig. 9. Segment of a) Locator-Feature matrix, b) Carrier-Feature matrix, c) binary pattern, robust matrix *LCM* d) and of *LCBM* e).

The elements of ***LCM*** are maintained in ***LCBM*** where the equivalent elements of ***BP*** have the value one. The elements of ***LCM*** are set to zero in ***LCBM*** where the equivalent elements of ***BP*** have the value zero. The relationship between segment ***k*** of ***LCBM*** and segment ***k*** of ***LCM*** is the scalar $\boldsymbol{SR_k}$.

$$SR_k = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n} lcbm_{k_{i,j}}}{\sum_{i=1}^{m}\sum_{j=1}^{n} lcm_{k_{i,j}}} \qquad \text{(m/n = numbers of rows/columns)} \qquad (6)$$

$\boldsymbol{SR_k}$ is the basis of the embedding process and has a value range between 0 and 1. To embed a bit value ‘0’ respectively ‘1’ the image is changed by geometric warping so that 0 <= $\boldsymbol{SR_k}$ < 0.5 respectively 0.5 <= $\boldsymbol{SR_k}$ <= 1.

Analysis of the $\boldsymbol{SR_k}$ robustness to lossy compression shows that $\boldsymbol{SR_k}$ is suitable to carry the watermark. As shown in Fig. 10 the MAE (Mean Absolute Error) is very low. This error analysis considers already the error caused by the Locator-Feature based segmentation process.

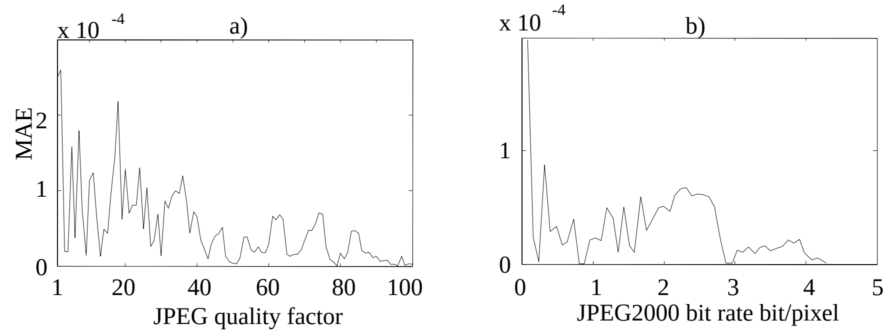

Fig. 10. Robustness of SR_k to a) JPEG and b) JPEG2000 compression

To embed the watermark bits, the image has to be warped. Therefore, a warping matrix is computed in a way that the new resulting $\boldsymbol{SR_k}$ have the wanted values. For example, see Fig. 11.

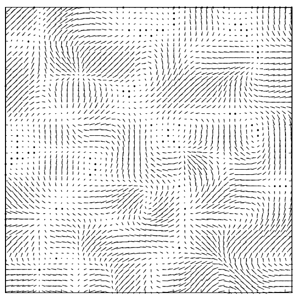

Fig. 11. Example of warping matrix gained by factor 10 for a better visualization.

The embedding process is computationally expensive. The largest amount of computing power is used to get the warping matrix. However, the watermarking extraction process doesn’t need the warping matrix. Hence, extracting the watermark bits needs less computing power. The extraction process requires the matrices ***LFM***, ***CFM*** and ***BP*** to realize the segmentation process and to compute ***SR*** for each segment. These values can be computed directly using the watermarked image. The original image is not needed. The watermark bit values ‘0’ or ‘1’ can be directly computed using the single $\boldsymbol{SR_k}$.

6 Results

The watermarking approach was tested for different gray scaled images with the size of 512x512 pixels. A maximal warping strength of one was used. Hence, the spatial position of a pixel is moved less than one by the warping process. The number of embedded bits respectively the number of segments is 20. An example can be seen in Fig. 12.

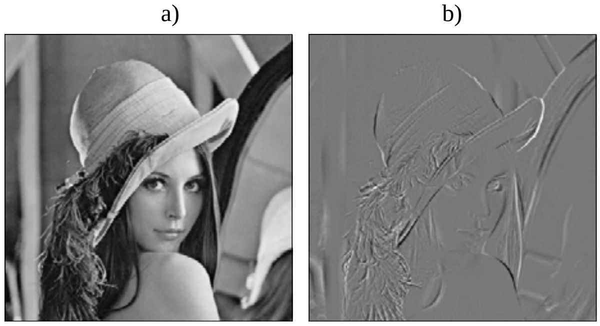

Fig. 12. Watermarked image „Lena“ a) and difference image between watermarked image and original b). The warping strength is gained by factor 3 for a better visualization.

The results of the robustness analysis are shown in Fig. 13. The robustness analysis considers the robustness of the segmentation process and the robustness of $\boldsymbol{SR_k}$. As expected, the watermark is robust to strong lossy compression. On a JPEG compression with quality factor 10, 92.9% of the embedded bits can be correct extracted. On a JPEG2000 compression with a resulting bit rate of 0.23 Bit/Pixel, 99.16% of the embedded bits can be correct extracted.

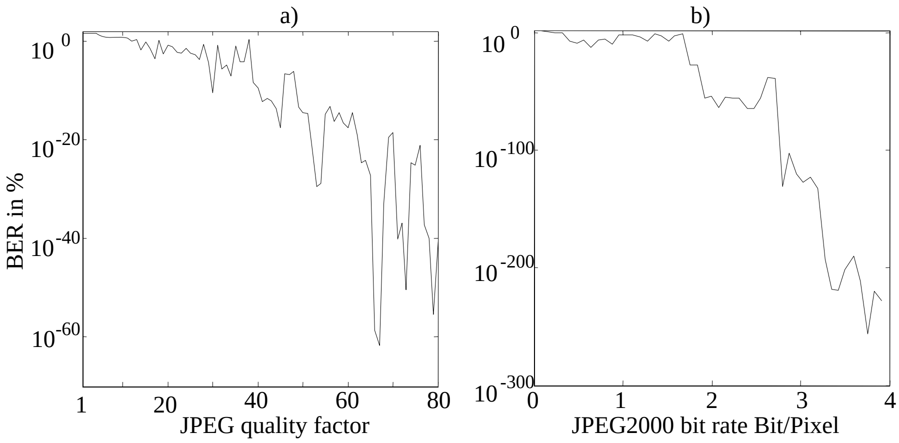

Fig. 13. Bit Error Rate (BER) of the embedded watermark bits after lossy compression with a) JPEG compression and b) JPEG2000 compression.

7 Conclusion

In this work, we propose a content-based watermarking approach basing on geometric warping. The suitability of geometric warping based watermarking approaches to achieve high watermark robustness to lossy compression is explained. The issue of hard decisions related to content-based watermarking is discussed. We propose a solution to prevent hard decisions increasing the watermark efficiency. Therefore, we introduce two new types of features and a feature-based segmentation process. The robustness of the segmentation process is analysed and presented. The proposed watermarking method offers the possibility to protect the watermark against unauthorized access. The watermark extraction process does not need the original image. Analyses confirm the expected high robustness to lossy compression.

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