A NEW UNCOMPRESSED-DOMAIN VIDEO WATERMARKING APPROACH ROBUST TO H.264/AVC COMPRESSION

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ABSTRACT

In this paper, we present a new video watermarking approach which is robust to efficient video coding standards such as H.264/AVC.

We show the contradiction between embedding watermarks in the irrelevant part of a video and using a lossy compression algorithm to reduce the video data rate. Because the compression algorithm removes irrelevant information, the watermark can not be recovered. To solve this problem, we propose the embedding of the watermark in the relevant part of the video but in an imperceptible manner. We realize this by changing the spatial position of object borders. We propose our new Normed Centre of Gravity (NCG) to describe these borders. Of course, lossy compression influences the NCG. We present a method to predict the strength of this influence. Hence, we can embed the watermark with a defined robustness to lossy compression. The watermarking is embedded by quantizing the NCG. We present a geometric warping process to quantize the NCG and embed the watermark payload with a defined robustness. To demonstrate the robustness we use the new and at present most efficient available compression standard H.264/AVC.

KEY WORDS

Watermarking, H.264/AVC, Normed Centre of Gravity

1. Introduction

Current information technologies base more and more on digital multimedia data. Compared with analogue data, digital data offers many advantages. It is possible to produce a lot of digital data in a very short time and it becomes more and more trivial to edit and finish the data. In contrast to analogue data, digital data can be endlessly copied without any loss of quality. However, this advantages results in disadvantages, too. The technologies to manipulate and copy data are often used in an illegal manner. Hence, there is a growing importance of applications such as data authentication, copyright and data hiding. Digital watermarking offers contributions in these fields. It describes techniques to embed additional information, the Watermark, into digital data [1]. Transparency, robustness and capacity are some important and application dependent properties of watermarking. For example, to embed copyright information, robust watermarks are required, whereas authentication uses fragile or semi-fragile watermarks. Especially in the case of transmission or storage of digital video, lossy compression is used to reduce data rates. Hence, the watermark has to be robust to the compression method.

There are three ways to embed a watermark into video data. The watermark can be embedded in the uncompressed domain, during the compression process or after the compression process. Watermarking during the compression process requires an implementation of the watermarking framework to the encoder. Qui et al. [2] use motion vectors to embed fragile watermarks during a H.264/AVC compression. In dependence of the payload, the motion vectors are changed to realize odd or even motion vector prediction errors. Watermarking after the compression process limits the embedding process to the current compression standard. Pröfrock et al. [3] use skipped macroblocks of H.264/AVC compressed videos to embed the watermark. Embedding the watermark in the uncompressed domain has the advantage, that the video data can be compressed with different standards and data rates. However, the embedded watermark has to be robust to the compression. At present in video data compression, the new H.264/AVC standard, developed for a broad range of applications, provides the highest coding performance [4], [5]. Compared with the MPEG2 standard, the H.264/AVC standard achieves a three times lower data rate at the same video quality.

In this paper, we propose a new uncompressed domain watermarking approach with robustness to H.264/AVC compression. We explain the contradiction between watermarking and using lossy compression algorithms. Therefore, we present a solution. We propose our new NCG (Normed Centre of Gravity) with predictable robustness to H.264/AVC compression. Our approach is based on QIM (Quantization Index Modulation ([6], [7])). We explain the NCG quantization process by using geometric warping. Afterwards, we present the results of our approach.

2. The Contradiction

Generally, the embedded watermark should be perceptually invisible. Hence, common approaches try to embed the watermark in the irrelevant and the perceptual invisible parts of the video (Figure 1). Generally, the PSNR (Peak Signal to Noise Ration) is used to measure the induced distortion caused by the watermark. Hence, these approaches try to spread the distortion to many pixels and try to reduce the amount of distortion of single pixels.

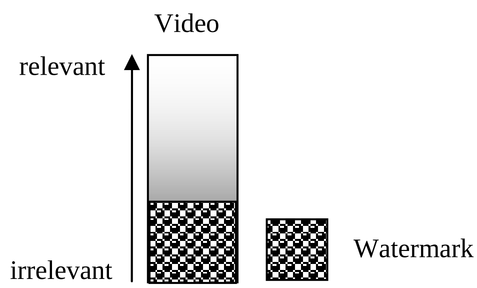

Fig. 1. Watermark embedding in the perceptual invisible (irrelevant) part of video data.

Lossy compression algorithms consist of two parts. The first part tries to remove irrelevant information (Figure 2) and the second part reduces the redundancy of the data. Usually, blocks or frames are decomposed into their frequency coefficients by using a transformation such as DCT or DWT. From the HVS (Human Visual System [8]) follows that lower frequencies are more visible than higher frequencies. Compression algorithms use this approach and quantize higher frequency coefficients more than lower frequency coefficients. Commonly, the PSNR is used to measure the visible quality degradation.

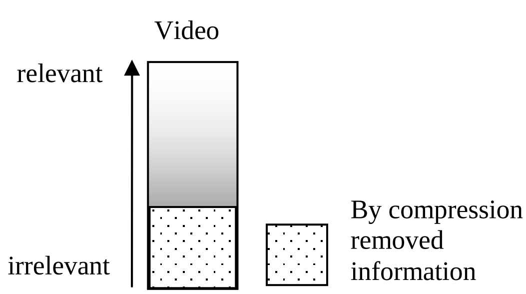

Fig. 2. Compression by removing perceptual invisible (irrelevant) parts of video data

We can summarize this in the following way. Commonly, the watermark is embedded in the perceptual invisible part of the video. The compression algorithms try to remove the perceptual invisible part of the video. Both systems use the same method to measure the perceptual quality degradation. That implies a contradiction. We can not embed a watermark in video parts which are removed during the compression process.

3. Proposed Solution

There are three possibilities to solve the problem of the contradiction between embedding uncompressed domain watermarks into the perceptual invisible parts of video data and using a lossy compression algorithm.

The first possibility is to find a gap in the current used compression algorithm. At present, no compression algorithm is perfect. Hence, the algorithm does not remove all perceptual invisible parts of video information. By finding this gap, the watermark could be embedded in the residual perceptual invisible parts (Figure 3 a)). A disadvantage of this way is, especially in new high efficiency compression algorithm, that it is difficult to find such gaps. A second disadvantage is the non-universal watermark approach. The watermark is only robust to the specific compression algorithm.

The second possibility to solve the problem of the contradiction is to embed the watermark with a defined strength. Hence, the watermark embedding degrades the video quality as less as possible and achieves robustness to the lossy video compression. Figure 3 b) shows the principle. Generally, the compression ratio is unknown. Hence, the watermark has to be embedded with a high strength to be robust to low as well as to high compression ratios.

The third possibility to solve the problem of the contradiction is to embed the watermark in the relevant and visible part of the video but in an imperceptible manner (Figure 3 c)). The advantage of this approach is a high robustness to compression algorithms.

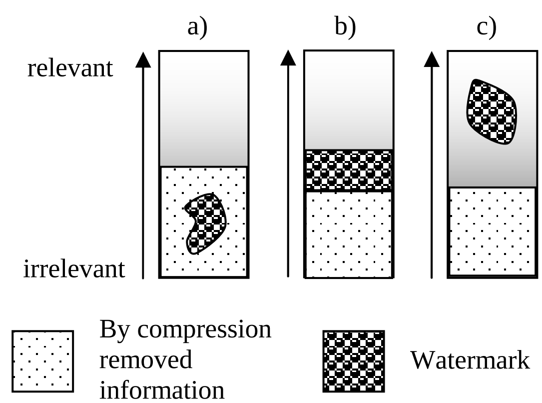

Fig. 3. Watermark embedding by using gaps a), a defined embedding strength b) and by using the relevant video information.

To realize this visible-imperceptible approach, we have to look at the used definition of relevance and visibility. All common compression standards use the PSNR to measure and compare quality of the compression algorithms. The visible-imperceptible approach can be realized if the watermark is visible according to PSNR definition but imperceptible if someone sees the video. In our approach we change border positions of objects to realize this approach. According to PSNR definition, object borders are definitively visible. Hence, they are relatively untouched by compression algorithms. Figure 4 shows an example. Assuming there are two objects in one frame with different gray-levels. Generally, the compression algorithm changes some gray-values slightly. However, the compression algorithm does not change the border position between these two objects. A change of the border position would result in heavy degraded PSNR-values. Hence every compression algorithm tries to maintain the border position.

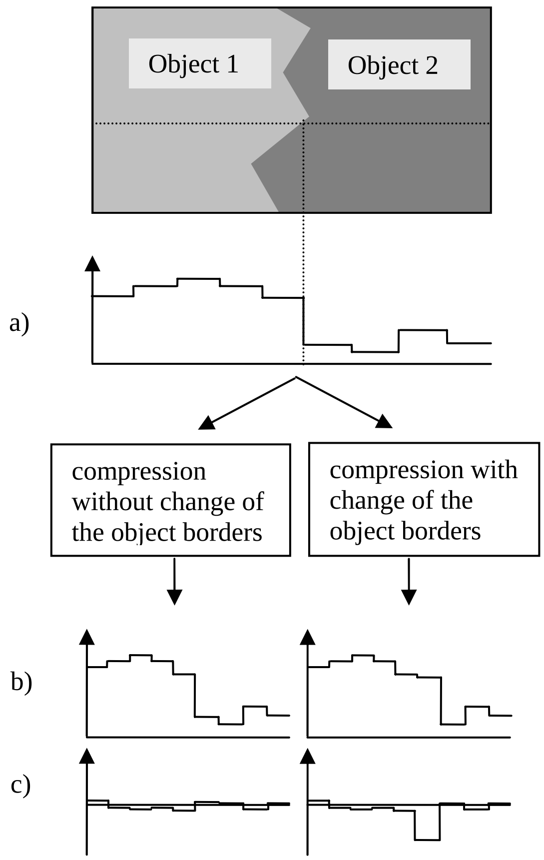

Fig. 4. Compression of object borders with a) original gray-level, b) compressed gray-level and c) difference of original and compressed gray-levels.

Figure 5 shows a practical example. The video “Bus” is compressed by using the H.264/AVC standard. The effect of removing the more irrelevant parts of the video can be clearly seen. However, the spatial position of the traffic sign is relatively unchanged. By quantizing the values of the x,y-coordinates of the traffic sign position, only by few pixels, we can embed a watermark. Therefore we use a QIM based approach. For example, if we use a quantization step size of 2, we can embed a watermark bit 1 by changing the x-position of the traffic sign to an odd value. To embed a watermark bit 0, we change the x-position of the traffic sign to an even value.

This watermark bit is robust to lossy compression. By comparing the original and the watermarked video, pixel by pixel, the differences can be clearly seen. Also the PSNR of both videos is low. However comparing the videos as a whole, the visual quality degradation can not be detected. The embedded watermark is visible but at the same time imperceptible and robust to common compression algorithms. To extract the watermark, the position of the traffic sign has to be computed.

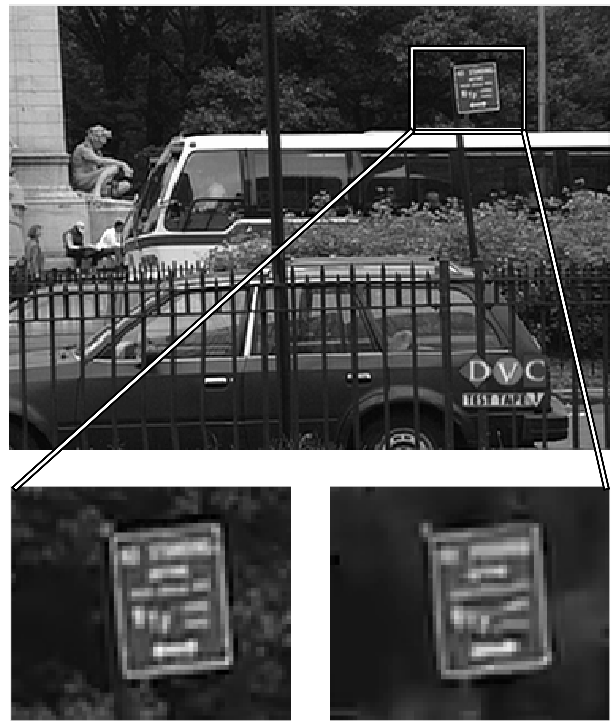

Fig. 5. Spatial position of the traffic sign is relatively unchanged after lossy compression with high (left) and low (right) data rates.

4. Approach of Using Object Borders

Object-borders achieve a high robustness to lossy compression algorithms. This can be used for watermarking but it is a non trivial problem and we have to consider some conditions. One problem is the watermark recovering. For example, we choose some objects and change their spatial position to embed the watermark. To recover the watermark, we have to find exact the same objects even though the video has been changed by compression. Hence, we are confronted with many known problems of object recognition [9]. To solve this problem, we use a block-based watermarking approach and describe only object borders inside single blocks. Now, we can decide, for each block, if we use one block to embed a watermark bit or not. Therefore, we developed the Normed Centre of Gravity (NCG). It is proposed in the following part.

4.1 The NCG

The NCG is similar to the gravity centre of one block. However, it is independent from the block borders and every gray-value of the pixel has the same influence to the NCG. We compute the NCG in the following way.

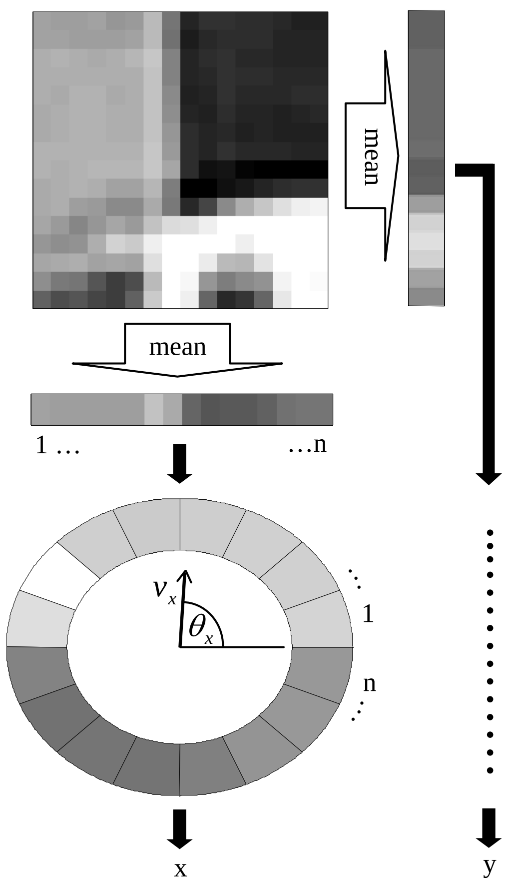

Fig. 6. Computing scheme of the NCG x,y-coordinates

First the mean values of the rows and of the columns of the block are computed. The results are two vectors m_x and m_y. The vector m_x is used to compute the x-coordinate of the NCG, the vector m_y is used to compute the y-coordinate. Therefore, the two vectors of mean values are arranged in two circles. Now, the two-dimensional vector v_k (k = x or y) is computed (equation 1).

$$v_k = \left(\begin{array}{c} \sum_{i=1}^{n} m_k(i) \cdot \cos\left(\frac{\pi}{n} + \left((i-1) \cdot \left(\frac{2 \cdot \pi}{n}\right)\right)\right) \\ \sum_{i=1}^{n} m_k(i) \cdot \sin\left(\frac{\pi}{n} + \left((i-1) \cdot \left(\frac{2 \cdot \pi}{n}\right)\right)\right) \end{array} \right) \qquad \textbf{(1)}$$

For each vector, the vector angles θ_x, θ_y and the vector lengths L_x, L_y are computed (following we use only L for L_x or L_y). The vector angles are used to compute the x,y-coordinates of the NCG (equation 2).

$$k = \frac{n \cdot \theta_k}{2 \cdot \pi} \qquad (k = \text{x or y}) \qquad \textbf{(2)}$$

Figure 7 shows an example. The NCG x-coordinate is 3.9 pixels and the y-coordinate 4.1 pixels.

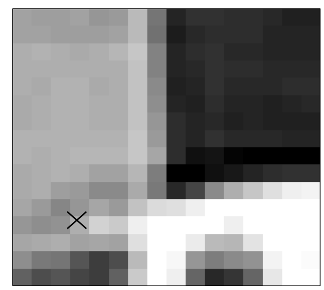

Fig. 7. NCG x,y-coordinates (cross) of an example block

4.2 Advantage of the NCG

The advantage of the NCG is the predictable robustness to compression algorithms. As already mentioned, compression algorithms try to maintain the object borders. Hence, the NCG of blocks with distinct object borders is robust to compression algorithms and the NCG of blocks without object borders is not robust to compression algorithm. Distinct object borders result in high vector lengths L_x and L_y. We use this vector lengths to predict the robustness of the NCG x,y-coordinates. Figure 8 shows an example. We use the videos “Bus”, “Horse”, “Horse2”, “Foreman” and “Waterfall” to compute the NCG for blocks with a size of 16x16 pixels. By using a H.264/AVC coder we compressed the videos with different quality parameters QP (higher QP yield lower data rates).

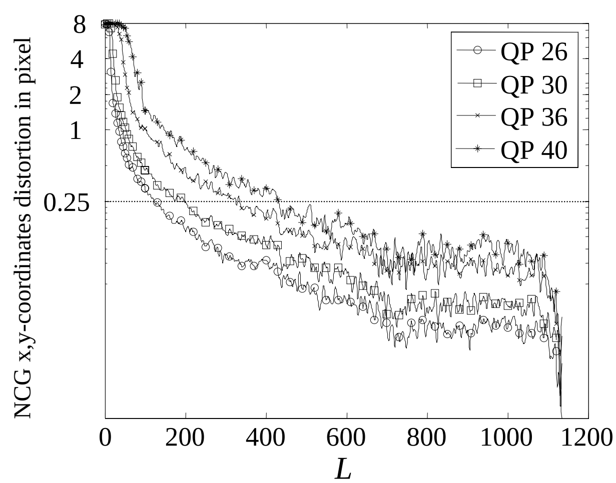

Fig. 8. NCG distortion depending on the NCG vector length L

The NCG x,y-coordinates distortion decreases with an increasing vector length L. As shown in Figure 8, the distortion for $L > 430$ is lower than 0.25 pixels for compression rates up to $QP \leq 40$. Hence, we can embed a watermark by quantizing the values of the x,y-coordinates of blocks with $L > 430$ by using a quantization step size of one. This watermark is robust to compression rates up to $QP \leq 40$.

5. Embedding Process

5.1 Embedding by NCG Quantizing

The first step to embed the watermark is to define the vector length $L_{\min}$ which ensures the required robustness. Afterwards, the blocks with $L > L_{\min}$ are chosen. To embed one watermark bit, the values of the x,y-coordinates of the NCG are quantized. The quantization is done by geometric warping of the block. The direction and strength of warping depends on the original and the quantized NCG-coordinates. To prevent block artifacts to neighbor blocks, the warping process uses different weightings for the strength of warping the single pixels. The weighting is computed by a quadratic function (Figure 9 a)).

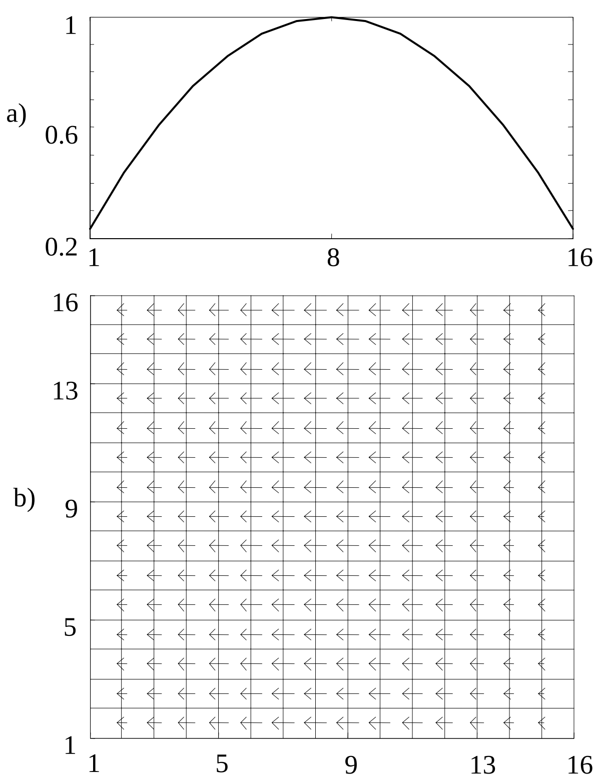

Fig. 9. a) weighting function of the pixels and b) example for geometric warping of the NCG x-coordinate

This geometric warping process is used to change the NCG x,y-coordinates. Figure 10 shows an example. The x-coordinate is quantized from 4.5 to 4.0.

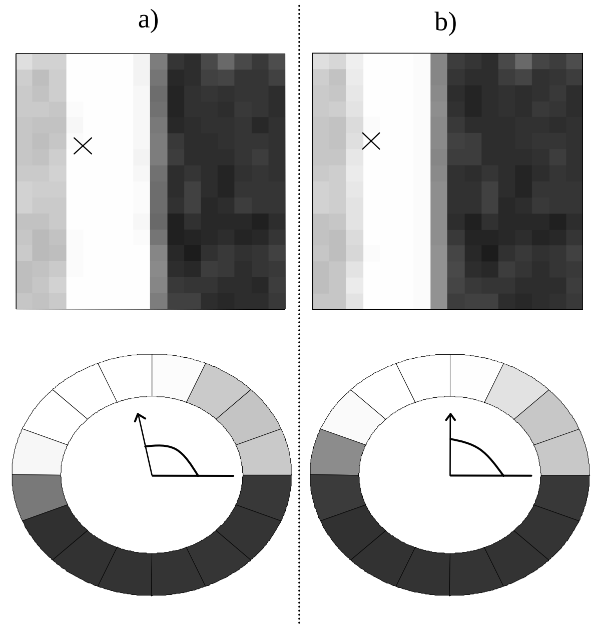

Fig. 10. Block with NCG before a) and after b) x,y-coordinate quantization.

5.2 Results

To test our approach, we embed watermarks in standard videos “Bus”, “Horse”, “Horse2”, “Waterfall” and “Foreman”. The video resolution is 352x288 pixels. We use only the Y-part of the YUV-videos. We use a quantization step size of one.

The robustness of the embedded watermark is defined by $L_{\min}$. We vary $L_{\min}$ between 121 and 430 and achieve robustness to H.264/AVC compression with QP between 26 and 40.

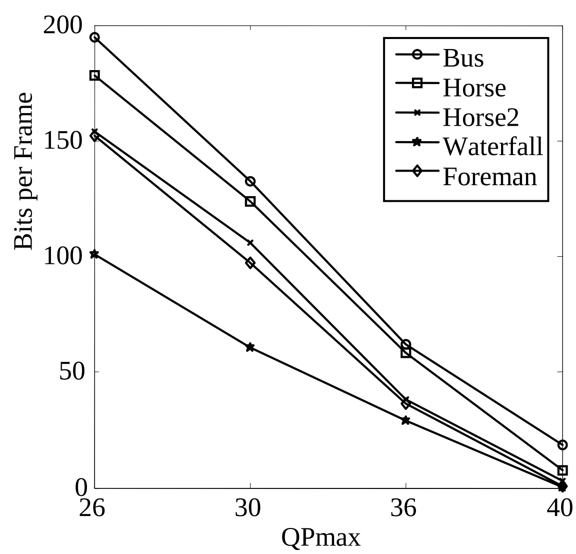

Fig. 11. Capacity in Bits per frame

The watermark capacity depends on the video data and the chosen L_{min}. Figure 11 shows the results. As expected, the capacity of videos without distinct objects, such as "Waterfall", is lower than in videos with distinct objects, such as "Bus".

The watermark results in visible artifacts as shown in Figure 12 b) and c). However, the watermark is imperceptible if viewers don't compare pixels but see the video as a whole. The frame in Figure 12 a) contains 22 watermarked blocks. For example, the wooden bole in the bottom right corner contains six of them. But, without comparing the original pixels with the changed pixels nobody is able to notice these blocks.

To extract the watermark bits, the blocks with $L > L_{min}$ are chosen. From the NCG coordinates of the chosen blocks the embedded bit values can be computed.

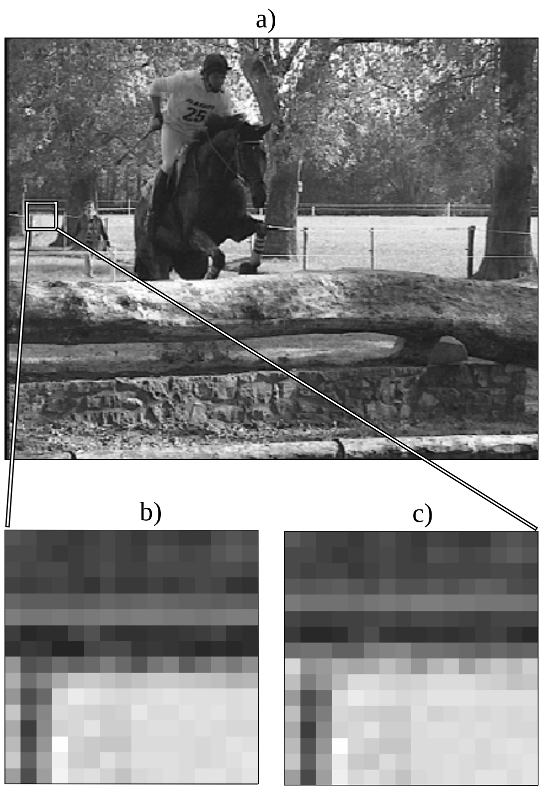

Fig. 12. Watermarked frame of "Horse" a), original block b) and watermarked block c)

6. Conclusion

In this paper, we present a new block-based video watermarking approach which is robust to the efficient video coding standard H.264/AVC. We show the contradiction between embedding watermarks in the irrelevant part of a video and using a lossy compression algorithm to reduce the video data rate. We present solutions to this problem and propose to embed the watermark in the relevant and visible part of the video but in an imperceptible manner. We change the spatial position of object borders by quantizing our new Normed Centre of Gravity (NCG). Therefore, we present a geometric warping process. The advantage of the NCG is the predictable robustness to lossy compression algorithms. We demonstrate the robustness by using the new compression standard H.264/AVC. We analyze and show that the watermark capacity depends on the video data. With this approach we can embed watermarks, which are used for data hiding, copyright protection and authentication, with a defined robustness to lossy compression algorithms.

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