DIGITAL WATERMARKING SIGNAL PROCESSING FOR QOS ASSESSMENT USING WAVELET TRANSFORM

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ABSTRACT

Digital watermarking of multimedia content has become a very active research area over the last several years. In this contribution, we match the conventional tracing watermarking procedure, based on embedding the mark in the Discrete Cosine Transform domain, to a technique that embeds the mark in the Discrete Wavelet Transform domain. The benefits of the proposed procedure are twofold: first, we minimize the perceptual distortions introduced by digital watermarking versus the conventional approach. Second, we show how it is still possible to trace the alterations suffered by the data through the communication channel without affecting the quality of the communications. Analytical results are used to show the benefits obtained in tracing watermarking for Quality of Service assessment by the new embedding domain confirming the validity of such approach.

1. INTRODUCTION

In the past decade, there has been an explosion in the use and distribution of digital multimedia data. PCs with Internet connections have made the distribution of multimedia data and applications much easier and faster [5]. In a networked environment like the World Wide Web, the crucial issue to be satisfied is the necessity to answer the ever-growing need to protect the intellectual property (copyright) of digital still images, video sequences, and audio from piracy attacks [7]. Therefore, there is an increase in concern over copyright protection of digital contents [1]. Digital media is more convenient than analog media in its usage, exchange of data, editing and storage. Moreover, digital media is complete without any distortion of data during the process of wide distribution through electric wave and network as well [2]. However, because of such characteristics, it is possible to duplicate the data and thus, many illegal trades often occur through the network. The aim of a controlled distribution of multimedia data can be reached developing suited signal processing techniques, such as digital watermarking.

Although copyright protection was the very first application of watermarking, different uses have been recently proposed in the literature. Fingerprinting, broadcast monitoring, data authentication, multimedia indexing, content-based retrieval applications [8]-[10], are only a few of the new applications where watermarking can be usefully employed. When these techniques are used to preserve the copyright ownership with the purpose of avoiding unauthorized data duplications, the embedded watermark should be detectable. In particular, an unconventional use of fragile watermarking has been recently proposed to blind estimate the Quality of Service (QoS) of a video-communication [4], embedding the mark in the Discrete Cosine Transform (DCT) domain. Indeed, there are a number of desirable characteristics that a watermark should exhibit [3]. It at least should comply with the following two basic requirements for image watermark: first, the digital watermark should not be noticeable to the viewer (i.e. transparency of digital watermark). Second, the digital watermark is still present in the image after distortion and can be detect by the watermark detector (i.e. robustness of digital watermark to image processing). The key to the watermarking technique is to compromise between the two aforementioned requirements.

Addressing some of these issues, this work extends previous simulation analyses [4] discussing some improvements on tracing watermarking obtained from embedding the mark in the Discrete Wavelet Transform (DWT) domain. The benefits of the proposed procedure are twofold: first, we minimize the perceptual distortions introduced by digital watermarking versus the conventional DCT technique [4]. Perceptual quality refers here to the imperceptibility of embedded watermark data within the host signal. In most applications, it is important that the watermark is undetectable to a user. This ensures that the quality of the host signal is not perceptually distorted, and does not indicate the presence of the watermark. Second, we show how it is still possible to trace the alterations suffered by the data through the communication channel without affecting the quality of the communications. As a consequence, using the same watermark intensity; we enhance the dynamic properties of the QoS evaluation system, because we need a smaller number of frames in order to extract the watermark from the video sequence, drastically reducing the time requested by the quality assessment procedure to be evaluated.
This work is organized as follows. In Section 2, the basic frameworks of the tracing watermarking setup are pointed up, while Section 3 shows the proposed watermarking algorithm in the DWT domain. The results of extensive performance analyses are provided in Section 4 using both objective and subjective indicators. Finally, the conclusions of the paper are drawn in Section 5.

2. FRAMEWORKS OF TRACING WATERMARKING FOR QoS ASSESSMENT

In this Section, the principles of the tracing watermarking procedure for the QoS assessment are introduced. As stated before, copyright protection of multimedia contents was the original target of watermarking, but some other applications are reported in the literature (fingerprinting, broadcast monitoring, data authentication, multimedia indexing, content-based retrieval applications, etc.). Usually, these techniques use a robust watermarking which means that the embedded watermark is supposed to be detectable (i.e. the watermark used for copyright protection should not allow the use of the watermarked content until it has not been correctly extracted). Recently, an unconventional use of fragile watermarking (the watermark should not be detectable when using the watermarked content) has been proposed to blind estimate the quality of service of a video-communication [4], and for QoS provisioning and control purposes [12]. The rationale behind the approach is as follows: the alterations suffered by the watermark are likely to be suffered by the data, since they follow the same communication link.

At the receiving side, the extracted watermark is compared with its original counterpart and the watermark degradations can then be used to evaluate the alterations endured by the data, obtaining a QoS index of the communication link (as explained in principles in Fig. 1). The Quality of Service is evaluated by comparing the extracted watermark with respect to the original one. In particular, its mean-square-error (MSE) is evaluated as an index of the effective degradation of the provided QoS. Thus, by knowing the end-to-end QoS, it is possible to adopt optimal strategies (e.g. pricing strategies) in terms of the QoS profiling for all the active users involved in the communication. In fact, such a QoS index can be usefully employed for a number of different purposes in multimedia communications such as: control feedback to the sending user on the effective quality of the link; detailed information to the operator for billing purposes and diagnostic information to the operator about the communication link status [11]. The first experimental results obtained in [4] show the capability of this unconventional use of watermarking techniques to trace the alterations suffered by the data through the communication channel. This quality assessment method can be applied both to uncompressed and compressed video sequences [4]. In the first case, the watermark embedding is performed on the data before coding, whereas in the second case, watermark embedding is performed on the coded bit stream.

Therefore, it can be used to estimate both the degradations introduced by the cascade coder-channel, as when the data are first coded and then transmitted through a non-ideal channel, and the ones introduced only by the channel.

Fig. 1: Idea of tracing watermarking: the watermark degradations can be used to trace the alterations endured by the data.

3. PROPOSED ALGORITHM

In this Section, the watermark embedding and extraction processes are described. Spatial spread-spectrum techniques [6] perform the watermarking embedding. In practice, the watermark (narrow band low energy signal) is spread over the image (larger bandwidth signal) so that the watermark energy contribution for each host frequency bins is negligible, which makes the watermark near imperceptible.

More in details (see Fig. 2), a set of uncorrelated pseudo-random noise (PN) matrices (one per each frame and known to the receiver) is multiplied by the reference watermark (one for all the transmission session and known to the receiver). Like in spread-spectrum techniques, the use of different spreading PN matrices assures that the spatial localization of the mark is different frame by frame, so that the watermark visual persistency is negligible. Moreover, the method is robust against permanent bit errors, due to either the physical network or its management (e.g. multi-path of the transmission channel, multi-user interference, excess loading factors, etc.). After generating the marks, the embedding of the tracing mark is performed in the DWT domain. The watermark is randomized by the PN matrices and added to the DWT of each frame. After the inverse DWT, the whole sequence is coded by a video coder (either MPEG2 or MPEG4 coders) and transmitted. In practices, the watermarks are embedded in a (large) number $M$ of the luminance I-frames.
In this way, the watermark is affected only by the channel’s errors and at the receiver side the estimation of the degradations affecting the received mark can be used to provide quality assessment of the channel. The result is that the spatial localization of the mark is different frame by frame, so that the visual latency perception is negligible and, on the other hand, it is robust against permanent bit errors, due both to the physical network or its management (e.g. multi-path of the transmission channel, multi-user interference, excess loading factors, etc.). The receiver implements video decoding as well as watermark detection. In fact, at the same time after decoding of the video stream, a matched filter extracts the (known) watermark from the DWT of each \( n \)-th received I-frame of the sequence. The estimated watermark is matched to the reference one (despread with the known PN matrix). The matched filter is tuned to the particular embedding procedure, so that it can be matched to the randomly spread watermark only. It is assumed that the receiver knows the initial spatial application point of the mark in the DWT domain.

The Quality of Service is evaluated by comparing the extracted watermark with respect to the original one. In particular, its mean-square-error (MSE) is evaluated as an index of the effective degradation of the provided QoS. On the other hand, this metric represent an objective indicator to evaluate the performance of the embedding process. This means that it gives poor information about the quality of the transmitted data (video sequences) really perceived by the final user (i.e. it may not be a perfect predictor of perceived quality). A metric which conversely provides subjective information about the perceived quality of the image (and of the video sequence) after the watermarking process is the video quality metric (VQM). This latter indicator reaches values near zero when degradations are imperceptible in the image; otherwise its value grows up as the image quality decreases, according to the National Telecommunications and Information Administration (NTIA) model [13]. VQM is intended to replace human evaluation with evaluation by machine. To accurately simulate human judgment, it must include some aspects of the human visual system [14]. In the next Section, we are showing the advantages obtained by the new embedding domain (DWT) as well as in terms of both objective (MSE) and subjective (VQM) indicators.

### 4. SIMULATION RESULTS

Several simulations have been made to detect the sensitivity of digital watermark to two different degradation sources: the noisy channel affects the video quality and the co-decoder itself affects the perceived image quality. In practice, the decoding quality depends on three factors: 1) the multiplying factor of the quantization matrix: as it increases the video quality also decreases; 2) the bit-rate: as it increases it improves the video quality; 3) the number of intra-coded frames. To evaluate the sensitivity of the method to the degradations due only to the channel, tests have been performed with different values of bit error rate (BER) using the same coder quality. In all the following simulations the scaling factor regarding the watermark intensity has been set equal to 0.04, according to [4]. Increasing this value, the mark becomes more evident and a visual degradation of the video occurs. On the contrary, by diminishing its value, the mark can be easily removed by the coder and/or channel’s errors.

From the operating viewpoint, we are interested in the actual video over a given communication link determined by the (booked) maximum bit rate. In other words, the target quality is fixed by the negotiated channel capacity, while the actual quality depends also on the symbol errors introduced in the received data stream by the physical link, due to background noise as well as multi-path channel and interference effects. Such transmission errors are modeled as a random Poisson process, characterized by a parametric probability of symbol error (proportional to the BER). Then, the actual quality needs to be detected by an in-service quality assessment measure, such as the tracing watermarking technique here discussed. For this purpose, a number of simulations have been carried out. In Fig. 3, the MSE of the estimated watermark with respect to the original one ver-
sus the BER for MPEG-4 coded video sequences at different compression ratio have been considered. In particular, Figure 3 reports here the MSE of the watermark extracted from the MPEG-4 “Carphone” (fig. 3a) and “News” sequences (fig. 3b) versus the BER of a simulated link for several (target) bit-rates. It is worth noting that the MSE of the extracted watermark increases when the BER increases and the bit rate decreases. This is in accordance with the perceptual degradation that the video suffers at increasing BER and decreasing bit rate. As shown in Fig. 4, the quality degradation of the watermark embedded into the host video has the same behavior of the one affecting the video, as happened before realizing the embedding in the DCT domain. However, the MSE represents an objective indicator to evaluate the performance of the embedding process. In order to evaluate the information about the perceived quality of the image (and of the video sequence) after the watermarking process, the video quality metric (VQM) is provided. In Fig. 5, the VQM of the two MPEG-4 video sequences “Carphone” and “News” is presented. As it can be easily seen from the graphs, the curves related to the embedding in the DWT domain are always lower than the others (in the DCT domain). This means that the perceptual degradations introduced by the watermark embedding process in the image have been minimized using the DWT domain as the domain for the embedding process instead of using the DCT domain.

The obtained results evidence the sensitivity of the watermarking quality index to the actual quality for given target quality levels and show the capability of this unconventional use of watermarking techniques to still trace the alterations suffered by the data through the communication channel. Moreover, the use of the DWT domain as the watermark embedding domain introduces less artifacts and alterations in the watermarked video sequence.

Fig. 3: MSE (normalized to 1) of the estimated watermark with respect to the original one at different compression ratio for the MPEG-4 coded video sequences: a) “Carphone”; b) “News”.
5. CONCLUSIONS

In this contribution, we matched the conventional tracing watermarking procedure, based on embedding the mark in the Discrete Cosine Transform domain, to the technique that embeds the mark in the Discrete Wavelet Transform domain. Tracing watermarking has been adopted as a technique to provide a blind measure of the quality of service of the communication link. The performance of the proposed method has been analyzed by wide simulation trials, focusing on multimedia communications environments. Analytical outcomes have been finally used to show the benefits obtained in tracing watermarking by the new embedding domain, as well as in terms of mean square error and video quality metrics.

According to the obtained results, the sensitivity of the new embedding domain outperforms the DCT approach as well as in terms of objective (mean square error) and subjective (video quality metrics) indicators.

6. REFERENCES


**Fig. 5:** VQM of the video-sequence versus the BER of the simulated communication link for: a) the watermarked MPEG-4 “Foreman” sequence; b) the watermarked MPEG-4 “News” sequence.