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A Framework for Evaluating Wavelet based Watermarking for Scalable Coded Digital Item Adaptation Attacks

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ABSTRACT

A framework for evaluating wavelet based watermarking schemes against scalable coded visual media content adaptation attacks is presented. The framework, Watermark Evaluation Bench for Content Adaptation Modes (WEBCAM), aims to facilitate controlled evaluation of wavelet based watermarking schemes under MPEG-21 part-7 digital item adaptations (DIA). WEBCAM accommodates all major wavelet based watermarking in single generalised framework by considering a global parameter space, from which the optimum parameters for a specific algorithm may be chosen. WEBCAM considers the traversing of media content along various links and required content adaptations at various nodes of media supply chains. In this paper, the content adaptation is emulated by the JPEG2000 coded bit stream extraction for various spatial resolution and quality levels of the content. The proposed framework is beneficial not only as an evaluation tool but also as design tool for new wavelet based watermark algorithms by picking and mixing of available tools and finding the optimum design parameters.

Keywords: Watermarking, wavelet, embedding, robustness, content adaptation.

1. INTRODUCTION

With the standardisation of JPEG2000 which uses DWT as its underlying technology, more focus has been given in wavelet domain watermarking schemes. Although number of wavelet based watermarking schemes are available, research community always lacks a common formal framework to compare new algorithms against other available schemes in a controlled experimental environment. For example, to evaluate the performance of an embedding method when all other parameters like, the wavelet kernel, number of decomposition levels and the choice of subbands are fixed. There have been efforts made on the evaluation of watermarking technologies such as Stirmark[1] and Checkmark.[2] Most of these frameworks provided various attacks and focused on evaluating algorithms' robustness those attacks. In another example, Watermarking Evaluation Testbed[3] facilitated a framework that enables different algorithms to test and check robustness against various attacks. But it is very useful to provide a common framework to compare the new algorithms with the existing ones in a controlled way, both in terms of the embedding performance and robustness. All current evaluation frameworks are based on the common attacks such as cropping, rotation, scaling, filtering, compression and etc. But with the increased use of the scalable coded media in multimedia usage, the MPEG-21 part-7 digital item adaptation (DIA) based content adaptation process to support universal multimedia access (UMA), has been a type of attack, the watermarked media is facing and widely gone unnoticed by the watermarking community. In this paper we present a framework to mainly address these two points.

Main objectives of this new framework, *Watermark Evaluation Bench for Content Adaptation Modes (WEBCAM)*[*], are:

1. To provide a controlled experimental environment for wavelet based watermark evaluation. We achieved this by dissecting commonly used wavelet based watermarking algorithms into basic modules and fitting them into a common watermarking framework.
2. To identify new watermarking schemes by choosing various modules and parameters from this common framework which also can be used as a research and learning tool for wavelet based watermarking.

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[*]The latest version of WEBCAM is available for download from http://svc.group.shef.ac.uk/webcam.html.

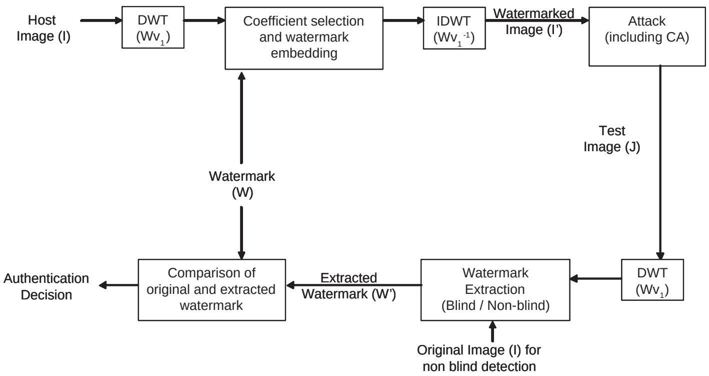

Figure 1. Block diagram of complete WEBCAM system architecture.

3. To provide tools to emulate scalable coding based content adaptation (MPEG-21 Part-7) attacks and tools to evaluate watermark robustness to such attacks. In addition, this framework also intends to facilitate tools for the traditional attacks such as rotation, cropping, filtering and etc. so that a complete evaluation scheme is available for the controlled experiments.

In this paper, we will discuss the systems architecture of this WEBCAM framework and the thought process motivated its design and demonstrate its capability in achieving above three objectives.

2. THE SYSTEMS ARCHITECTURE

The WEBCAM framework provides a controlled experimental set to evaluate the wavelet based watermarking algorithms as stated in objective one. Most of the wavelet based watermarking schemes follow a similar approach and these schemes can broadly be divided into two groups: uncompressed domain and joint JPEG2000 compressed domain watermarking.

Uncompressed domain watermarking is independent of the compression schemes and the watermark embedding is performed on the uncompressed images. Many such algorithms are available in the literature.[4–12] We have dissected these algorithms in modules which is shown in Fig. 1. A forward DWT is performed on the image (I) to be watermarked. Now an algorithm is applied to modify the wavelet coefficients to embed the watermark information. An inverse DWT which is similar to the forward DWT produces the watermarked image (I'). To check the robustness of the scheme various attacks including content adaptation such as JPEG2000 is applied to the watermarked image and as a result a test image (J) is produced for the authentication purpose. A watermark detection scheme which is reverse to the embedding is applied after a forward DWT operation on the test image (J) for the watermark authentication. An original non watermarked image is required for a non-blind watermarking scheme whereas for a blind watermarking algorithm the watermark is extracted from the test image without any original image reference.

Joint JPEG2000 compressed domain watermarking schemes are implemented by inserting watermark information in the JPEG2000 pipeline.[13–19] A block diagram of this kind of schemes are shown in Fig. 2. In a

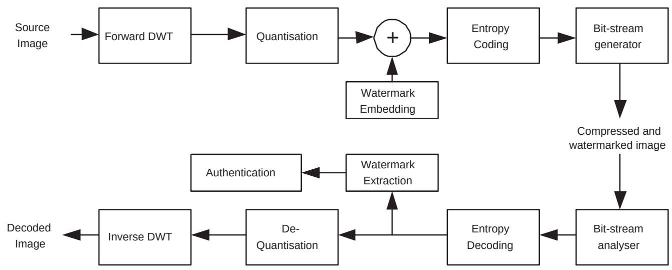

Figure 2. Joint JPEG2000 compression domain watermarking in JPEG2000 coding pipeline.

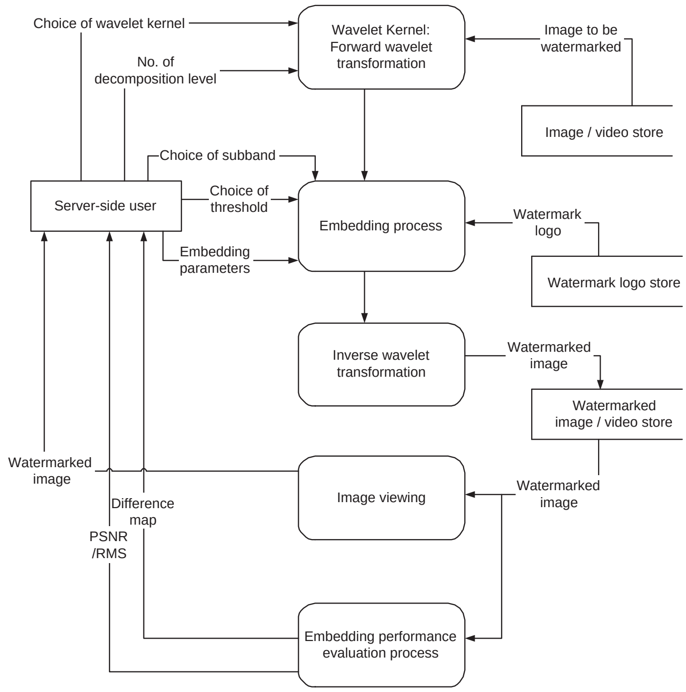

Figure 3. Block diagram of watermark embedding procedure.

JPEG2000 pipeline the wavelet coefficients are quantised and entropy coded before bit stream generation. The watermark embedding is normally performed after the quatisation step and before the entropy coding. The embedding parameters such as subband selection, coefficient selection, or an embedding algorithm are similar to the uncompressed wavelet domain watermarking schemes. After any scalable adaption of the JPEG2000 bit stream, the watermark is extracted during the bitstream decoding operation as shown in the block diagram.

In both the types of wavelet domain watermarking schemes, the embedding and the extraction procedures can be generalised into common modules which are discussed under embedding and extraction subsections. We also discuss content adaptation block separately as a part of the evaluation framework.

2.1 Watermark Embedding

A variable parameter space is provided in the WEBCAM framework in order to evaluate the new and the existing wavelet domain watermarking algorithms in a controlled experimental environment. Functional blocks of the wavelet based algorithms are shown in Fig. 3. The forward wavelet transform is applied to the target image with a choice to select wavelet kernel from a set of available linear and non-linear wavelet kernels (*e.g.*, orthogonal, biorthogonal, Morphological and spatially adaptive wavelets). The wavelet coefficients are then modified according to the selected embedding procedure. The selection of the coefficient in a chosen subband is important in order to improve the imperceptibility and the robustness. A flexible choice of the subband selection and the coefficient selection is available in this framework. An inverse wavelet transform which is same as the forward wavelet kernel is then applied to produce the watermarked image. Finally the embedding performance is evaluated using the distortion metrics, such as, the mean square error (MSE), the Peak signal to noise ratio (PSNR) and the data hiding capacity.

It is observed that the basic embedding principle of the algorithms remains same and can be presented in Eq. (1). The modified coefficient $C'_{m,n}$ at (m, n) position is expressed as:

$$C'_{m,n} = C_{m,n} + \Delta_{m,n}, \tag{1}$$

where $C_{m,n}$ is the coefficient to be modified and $\Delta_{m,n}$ is the modification due to watermark embedding. We categorised the embedding procedures (coefficient modification process) into two main types: direct coefficient modification[4,6,8,11,12] and quantisation of a ranked ordered list.[7,9,20,21]

We map all direct coefficient modification schemes into the following generalised modification value combination.

$$\Delta_{m,n} = (a_1)\alpha(C_{m,n})^b W_{m,n} + (a_2)v_{m,n}W_{m,n} + (a_3)\beta C_w + (a_4)S_{m,n}, \tag{2}$$

where $\Delta_{m,n}$ is the modification value at (m, n) position, $a_1, ..., a_4$ are boolean variables to identify the presence of each of the components for a given methodology, $C_{m,n}$ is the coefficient to be modified, α is the watermark weighting factor, $b = 1, 2...$ is the watermark strength parameter, $W_{m,n}$ is the watermark value, $v_{m,n}$ is the weighting parameter based on pixel masking in HVS model, β is the weighting parameter in case of fusion based scheme, C_w is the watermark wavelet coefficient and $S_{m,n}$ is any other constant. Designing this framework in this way allows us to evaluate the effect of above different input design parameters.

Similarly we map the quantisation of a ranked ordered list based modification into the following relationship.

$$\delta = f(\alpha, C_{min}, C_{max}), \tag{3}$$

where α is the weighting factor and C_{min} and C_{max} are the local minimum and the local maximum values of the ordered list of coefficients, respectively. These methods vary by the way, the coefficients are chosen for the list, for example, choosing from the same subband (intra subband quantisation)[7] and choosing from different subbands of the same level (inter subband quantisation).[20,21]

After embedding, the inverse wavelet transformation of the associated wavelet base is performed to get the watermarked image. At this point, the framework computes the embedding performance metrics such as the distortion measure and the data hiding capacity.

2.2 Content Adaptation Attacks

As stated in the objective 3, MPEG-21 Part-7 based content adaptation process is realised in the framework. We have included two parts, namely, content adaptation of scalable coded bit stream and the emulation of transmission channel properties, as shown in Fig. 4, into the content adaptation module. The scalable coded bit stream is adapted at different transmission nodes based on the transmission speed, the transmission medium and

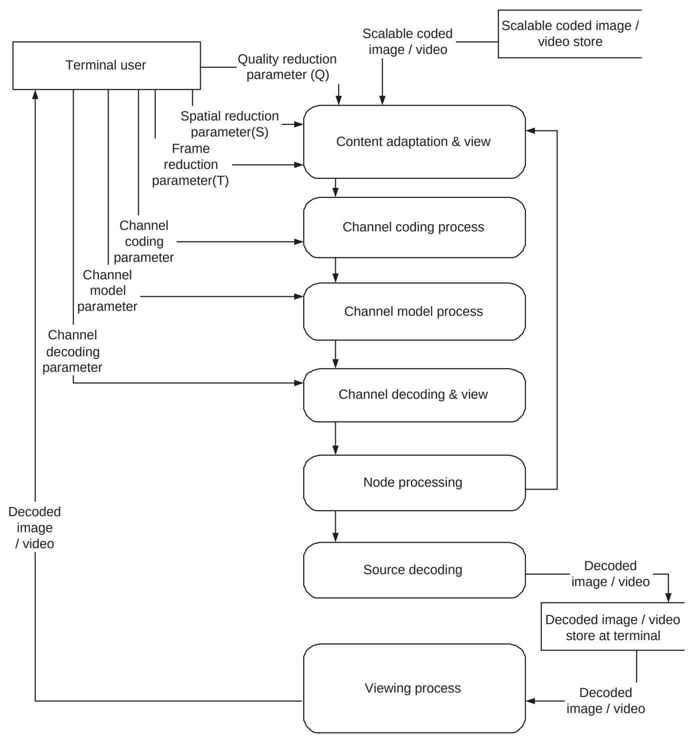

Figure 4. Block diagram of Content Adaptation attacks.

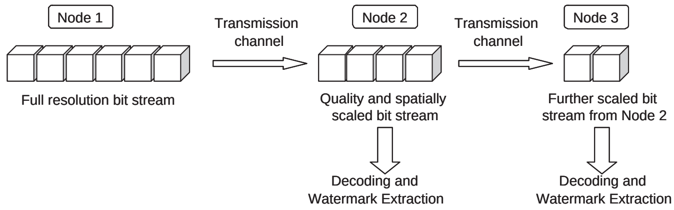

Figure 5. Scalable content adaptation process realisation.

the display device. For example, a full resolution bit stream is kept in the main server. To deliver this content to the end user we need to use transmission channel. The bit stream is adapted according to the channel capacity followed by channel coding, channel model for transmission. At the receiving node a channel decoding is done to reproduce the bitstream. This bit stream is either readapted and follows the same process to be transmitted to another node or decoded at the same node to be displayed at the user device. The bit stream at each node is preserved so that decoding of the bit stream and watermark extraction can be performed at each node as shown in Fig. 5. In phase-I of this framework we have adopted JPEG2000 based content adaptation scheme to implement this module. In later versions, we intend to support H.264/AVC Scalable extension as well.

2.3 Watermark Extraction and Authentication

The Watermark extraction procedure can be categorised in two types: non-blind[4,6](original image required) and blind.[7,20]The extraction procedure comprises of three basic modules: forward wavelet transformation, extraction algorithm and authentication decision (refer Fig. 6). The forward wavelet transformation module is similar to the one which is used for embedding. The extraction procedure follows the inverse algorithm of the embedding scheme. The watermark extraction is based on the majority voting rule of the extracted watermarks. Finally the authenticity module decides whether the extracted watermark matches the original one. The framework provides the facility to choose either the similarity correlation[4] or a Hamming distance measurement[20] to evaluate the authenticity.

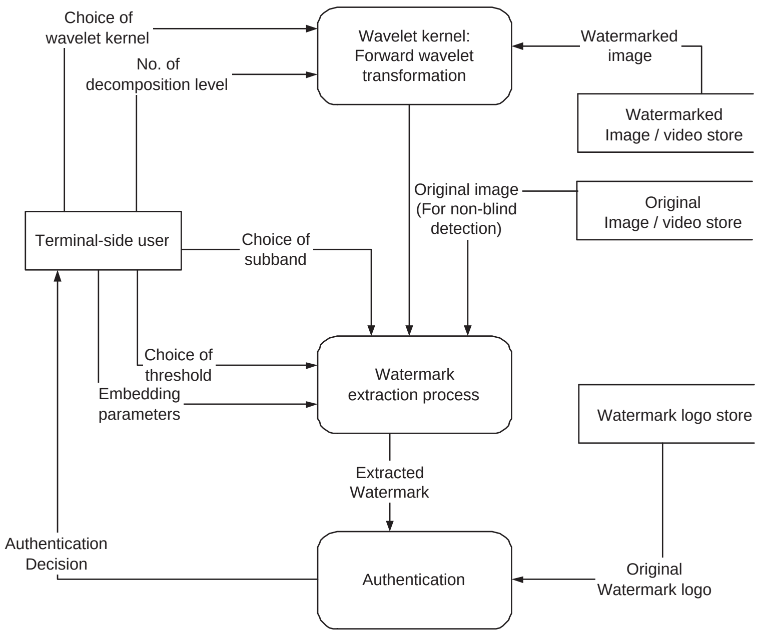

Figure 6. Block diagram of Watermark extraction procedure.

3. USAGE EXAMPLES OF THE FRAMEWORK

In this section, we demonstrate how WEBCAM is used for evaluating the watermarking performance with respect to embedding and robustness as in a controlled experiment. As stated in the objectives, it is possible to rebuild the algorithms discussed in the literature with different combination of input parameters available in WEBCAM as shown in Tab. 1. We also show the results of the experimentation with various combinations of the design

Table 1. Realisation of wavelet based algorithms using different combination of WEBCAM parameters

Method	Selection Coefficient $< a_1, a_2, a_3, a_4 >$	Subband Selection	Wavelet Kernel	No of Decomposition Level	Reference
Direct$(b = 2)$	$< 1, 0, 0, 0 >$	High	Haar	2	6
Direct$(b = 1)$	$< 1, 0, 0, 0 >$	All	Biorthogonal	3	4
Direct$(b = 1)$	$< 1, 0, 0, 0 >$	Low	Biorthogonal, Non-linear	3	22
Direct	$< 0, 1, 0, 0 >$	High	Any	4	8
Direct	$< 0, 0, 1, 0 >$	High	Orthogonal	4	12
Direct	$< 0, 0, 0, 1 >$	High	Any	2	11
Intra Subband	-	Low	Any	2	7
Inter Subband	-	High	Haar	1	20
Inter Subband	-	High	Any	2	21

parameters to create new watermarking schemes and evaluate their performances. For example, the embedding distortion performance (PSNR) for various types of wavelet kernels, choice of subband and the embedding methodology is shown in Fig. 7. A capacity-distortion plot is shown in Fig. 8 where distortion performance is compared for different host images in three different embedding algorithms with the consideration of data capacity.

Example results to evaluate and compare the robustness of different watermarking schemes in a controlled experimental set up are shown as listed below. In each case, the content adaptation is simulated for quality and resolution scalability. For the latter, we have considered bit stream extraction on full resolution and half resolution images. For the quality scalability, we have extracted bit streams at different bit rates. The example scenarios are:

1. Different methods - compared for a given set of wavelet kernel, embedding region (the choice of subband)

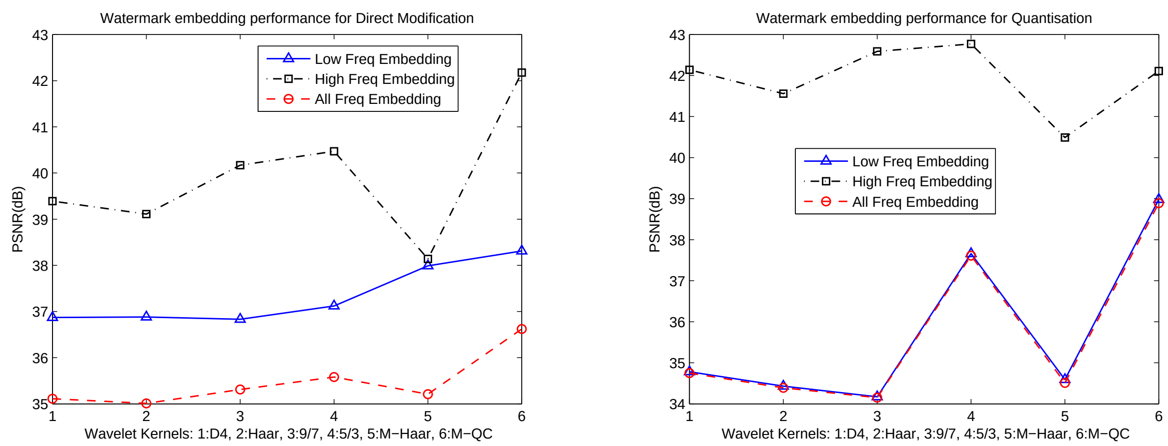

Figure 7. Watermark embedding distortion performance graph. *Column 1:* Direct modification. *Column 2:* Intra subband scanning

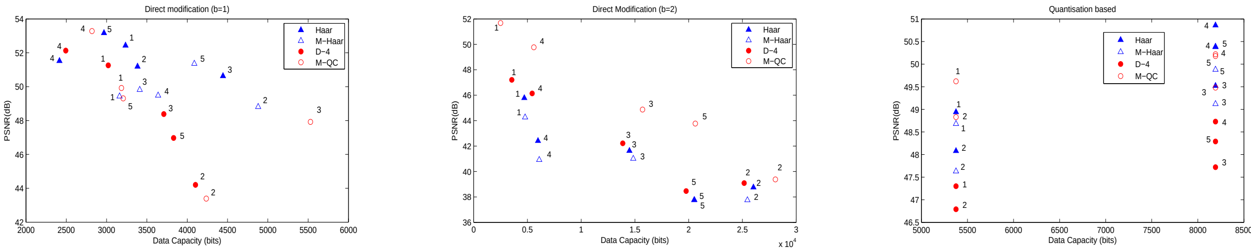

Figure 8. Rate distortion graph: PSNR vs data capacity for three different methods using different wavelets. 5 different images have been used for simulation. Image 1: Lena, Image 2: Mandrill, Image 3: Boat, Image 4: Girl and Image 5: House

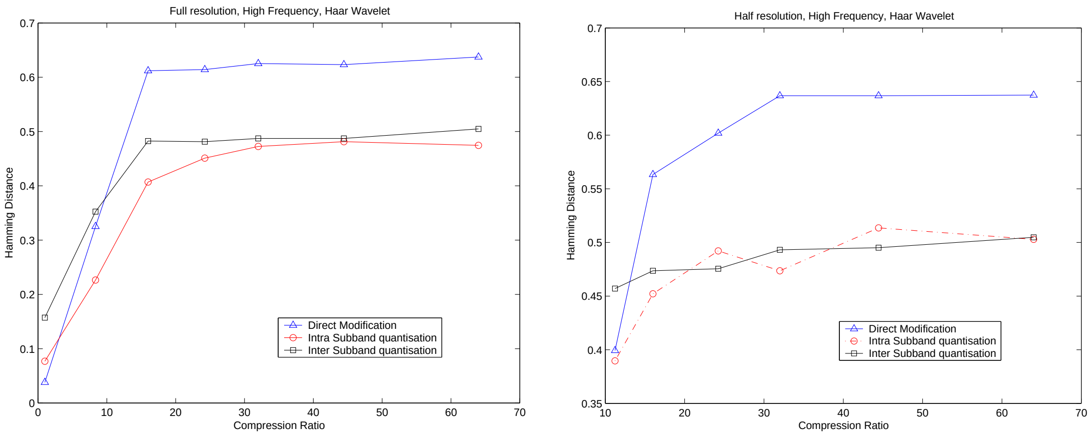

Figure 9. Evaluation of different methods with a given wavelet kernel, embedding region and no. of decomposition level. Hamming distance is measured for full resolution (*Column 1*) and half resolution (*Column 2*) with various compression ratio.

and number of decomposition level (as shown in Fig. 9).

2. Different embedding regions (the choice of subbands) - compared for direct modification method when other parameters are fixed (as shown in Fig. 10).

3. Different embedding regions (the choice of subbands) - compared for intra subband quantisation for a given given wavelet kernel and decomposition level (as shown in Fig. 11).

4. Different wavelet kernels - compared for direct modification (as shown in Fig. 12).

5. Different wavelet kernels - compared for intra subband quantisation for a given embedding region and decomposition level (as shown in Fig. 13).

4. CONCLUSIONS

We have presented the WEBCAM framework for evaluating wavelet based watermarks. We aimed to facilitate a controlled experimental environment for watermark evaluation and tools for emulating MPEG-21 digital item adaptation attacks present within the multimedia usage chains, which has been unnoticed as an attack by the watermarking community. In WEBCAM, we have dissected commonly used wavelet based watermarking algorithms into basic modules and fit them into a common framework. For formal evaluation of the watermarking algorithms on robustness to MPEG21 based scalable content adaptation, in this paper we have discussed the inclusion of JPEG2000 based content adaptation attacks and evaluated the robustness of various wavelet based watermarking algorithms to quality and resolution scalability based adaptations.

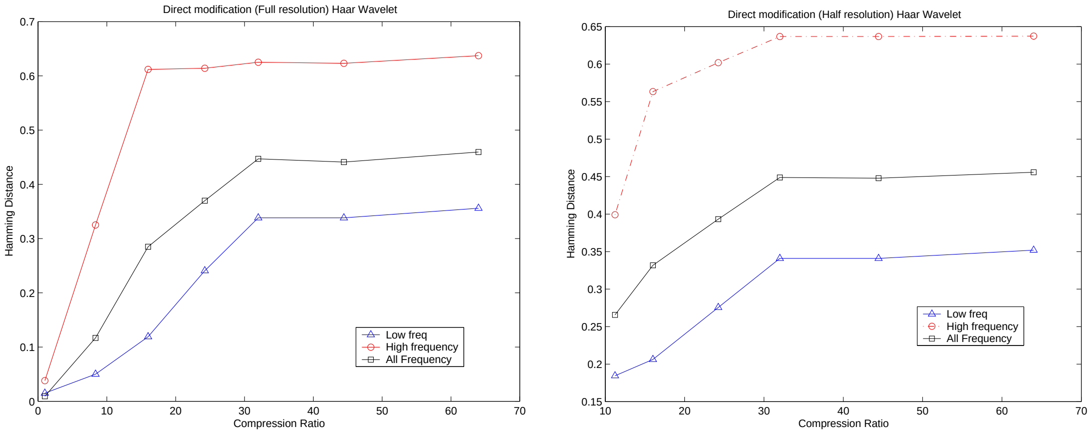

Figure 10. Evaluation of different embedding region with a given direct modification algorithm, wavelet kernel and no. of decomposition level. Hamming distance is measured for full resolution (*Column 1*) and half resolution (*Column 2*) with various compression ratio.

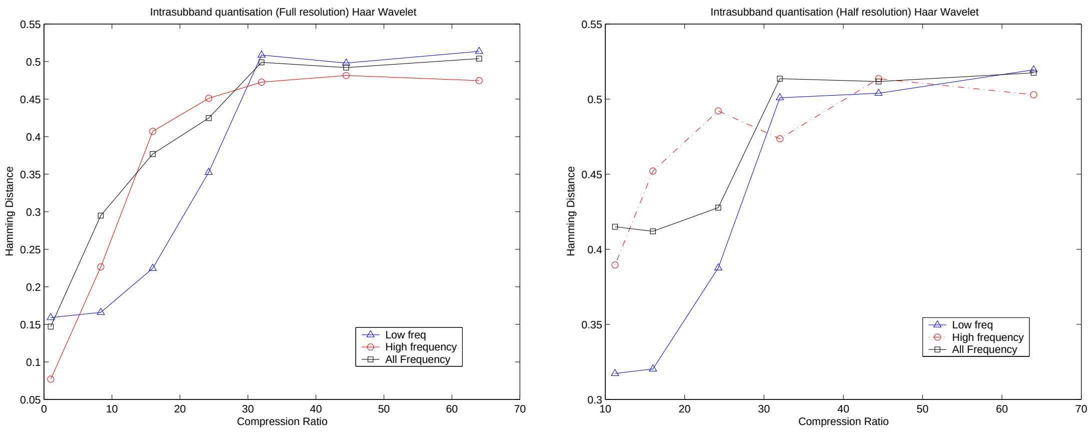

Figure 11. Evaluation of different embedding region with given intra subband quantisation algorithm, wavelet kernel and no of decomposition level. Hamming distance is measured for full resolution (*Column 1*) and half resolution (*Column 2*) with various compression ratio.

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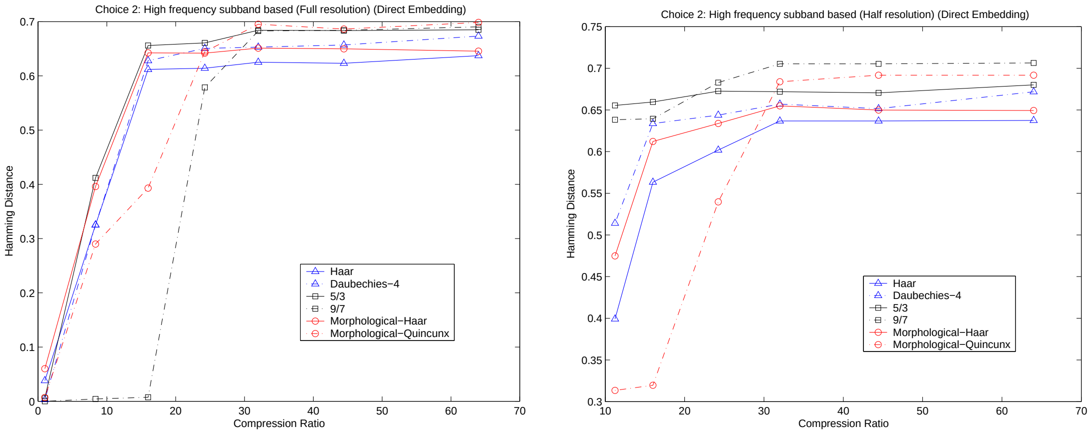

Figure 12. Evaluation of using different wavelet kernel with a given direct modification algorithm, selected embedding region and no. of decomposition level. Hamming distance is measured for full resolution (*Column 1*) and half resolution (*Column 2*) with various compression ratio.

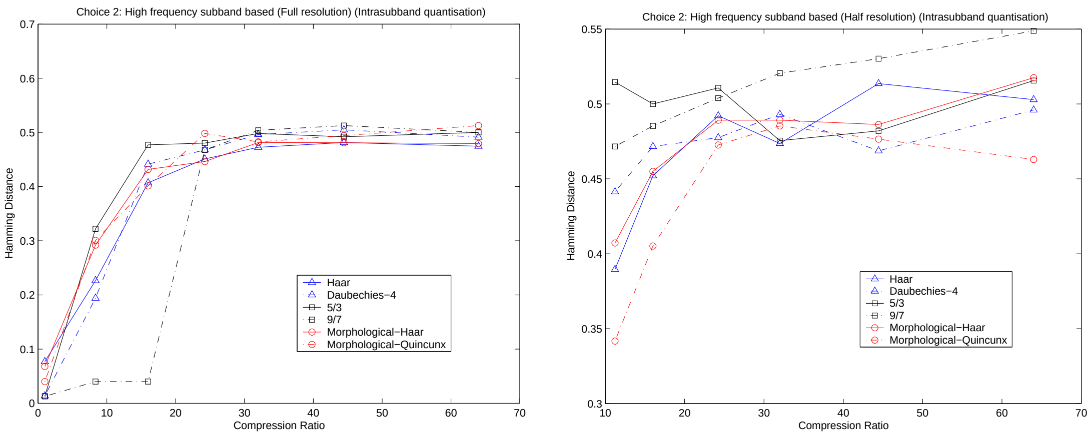

Figure 13. Evaluation of using different wavelet kernel with a given intra subband quantisation algorithm, selected embedding region and no. of decomposition level. Hamming distance is measured for full resolution (*Column 1*) and half resolution (*Column 2*) with various compression ratio.

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