A Wavelet Filter Evaluation for an Inter-Frame JPEG 2000 Adaptive Video Coding System

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A Wavelet Filter Evaluation for an Inter-Frame JPEG 2000 Adaptive Video Coding System [*]

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Abstract

In this paper, we present an evaluation of various wavelet filters in the context of a JPEG 2000 based inter frame video coding system both on software and on hardware side. The software system itself is based on coding of a combination of intra frames and/or differential frames. Motion indicators are introduced and performed on the differential frames to determine the motion content (high or low) of the frame on a block basis. These motion indicators are utilized to decide whether to code differential frames or intra frames, to form an adaptive Group of Picture structure. The usage of different wavelet filters (Daubechies-9/7, Daubechies-5/3, Haar, etc.) for intra/differential frames is investigated, where we mainly focus on coding time and average video quality of the video stream. We port this software system to a hardware system. Experiments exhibit the difference (both in implementation and performance) of using wavelet filters on software and on hardware system.

1 Introduction

Inter-frame based video coding is widely used in many video coding approaches, such as H.264 and MPEG-2. In addition, wavelet-based methods achieved tremendous success in still image coding (JPEG 2000). Among other techniques, a significant amount of classical wavelet based 2-D coders have been suggested in literature [8, 10, 11, 13, 18, 21, 22]) as well as the DIRAC codec [23] being the most well known one among these approaches. Motion JPEG 2000 (key part of JPEG 2000 standard) has had major success because of the Digital Cinema Initiatives (DCI) [12] coded video for releases in cinemas, by coding with Motion JPEG 2000. The high image quality of such intra frame coders, lack of block artifacts, and high efficiency make JPEG 2000 ideal for high-definition (HD) applications, such as digital cinema, and all HD capable applications [3]. Thus we considered this compression method as useful.

The main goal of this paper is to examine the performance of different wavelet filters and combinations based on a interframe based JPEG 2000 video coding system and to evaluate which ones fit different frame types. Various wavelet filters are already used in standard video coders such as the DIRAC codec [23, 24] and DCI JPEG2000 Encoders [5, 6, 12]. The Dirac codec defines 7 different wavelet filters used in the coding pipeline. The choice of the wavelet filter is depending on the target implementation of the Dirac coder. DCI encoders use the Daubechies 9/7 as the default filter, with the LeGall 5/3 as an alternative option [5, 6, 12]. The coders in [1, 8, 9, 20] use a combination of 5/3 wavelet filters. The usage of the Cohen-Daubechies-Feauveau 9/7 is performed in recent coders [11, 13, 19, 21, 22].

We perform an evaluation both on software and on hardware side and show how implementation (hardware and software) and results differ. We basically investigate the behavior of the biorthogonal Daubechies-5/3-wavelet (also referred as 5/3 or LeGall-5/3-wavelet) and the Daubechies-9/7-Wavelet

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(also referred as 9/7 or Cohen-Daubechies-Feauveau 9/7 or CDF 9/7) which are standard in the JPEG 2000 implementation and the orthogonal Haar wavelet. We evaluate the performance (both average visual quality and coding time consumption) of those filters in our framework. We use the orthogonal Haar wavelet, due to its short length and easy implementation; its energy conservation simplifies the design of a fast and straightforward video coder, because it is fast and it circumvents an increase of errors in the frequency domain (through its shortness).

Section 2 examines the software system as well as the wavelet filter options in our system. In Section 3 we exhibit how the wavelet filters can be implemented on the hardware platform. Experimental results comparing the software and the hardware implementation are presented in Section 4.

2 Software System

2.1 Baseline System

Figure 1 illustrates the structure of the baseline software system. In this system [25], at first the initial raw video frame is read in and encoded as an I-frame. For subsequent frames, a differential frame is computed between the current frame to be encoded and the reconstructed reference frame. This differential frame is then analyzed using a set of motion indicators [25]. Knowing the motion content of the differential frame helps us to determine whether to code an Intra or an differential frame. Hence, this leads to an adaptive GOP structure for the encoded video. The system is initially simulated on software side, where the encoding is done via the open source JPEG 2000 implementation of Jasper. Similar techniques have been proposed in the context of MPEG or H.26X [16, 27, 17]. We find significantly improved compression performance compared to Motion JPEG2000 (MJ2K) [25].

2.2 Wavelet filter Options

The free JPEG 2000 software codec (*Jasper*), which we are using, features two different wavelet filters to code the frames. All supported filters are based on 1-D 2-channel filter banks. The first filter used is the Daubechies-5/3-Wavelet filter which is the default filter: This is used for the lossless case, in which a reversible integer-to-integer transform is employed [7]. The second wavelet which is used in the *Jasper* implementation is the Daubechies-9/7-Wavelet: In the lossy case, a nonreversible real-to-real wavelet transform is used [2]. Using the software in default mode, the video sequence is coded with the 5/3 filter. Jasper uses a lifting implementation for its filters, which can easily adapted for our needs. Thus, we wanted to use additional wavelet filters. The significant shorter Haar wavelet [14, 15] for both intra and differential frame is implemented, by changing the lifting coefficients of the low and highpass filters of the Jasper implementation. In order to accomplish this, the array which contains the lifting coefficients is shortened and the three coefficients of the haar (1.0,-1.0,0) are used. Thus, it was no problem to build a combination of Haar and 9/7 and/or 5/3.

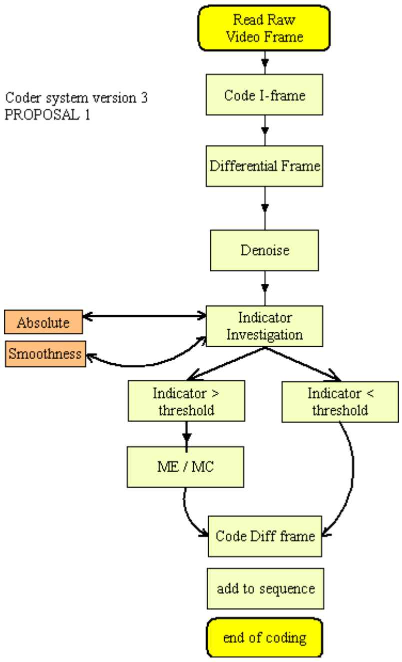


Figure 1. Basic coder design

3 Hardware System: Wavelet Filters

The hardware system [26] basically consists of a processing unit (ADSP-Blackfin 533 from Analog Devices) and a JPEG 2000 compression engine

(ADV202). Raw pixel data is passed on to the compression chip (ADV202) for encoding. The data is then deinterleaved and passed on to the wavelet transform engine on the ADV202 chip. Data is then decomposed into subbands and further the wavelet transform (WT) is performed. The wavelet engine can perform up to 6 wavelet decomposition levels on a tile. The wavelet engine on the ADV202 supports a 9/7 irreversible (using fixed tables) wavelet transform and the 5/3 wavelet transform in reversible and irreversible modes.

At the end of the wavelet engine's pipeline, the computed wavelet coefficients are then written to internal memory [4], and then stored in packets (JPEG 2000 compliant bitstream). Compressed video data is again ported to internal memory and to the main processing unit (Bf533).

On the hardware system, the switching between the different wavelet filters is achieved by simply changing the encode parameters (change the values in the encoding register) for each frame cycle. We concentrate on the computational effort of the combination of both filters, however, we used the 5/3 filters mainly on our differential frames, as well as the 9/7 on our intra frames. In the "Experiments" section, the performance of using these filters (as well as various combinations and usage with the Haar wavelet) is further examined.

4 Experiments

4.1 Software:

We have used the standard video test sequences Akiyo (100 frames), Carphone (100 frames) Claire (100 frames), Coastguard (100 frames), Foreman (100 frames), Garden (100 frames), Grandma (100 frames) and Paris (40 frames) in their respective standard resolution. The sensor we are using is a Olympus Camedia Master SP-510 UZ which is able to yield QCIF and CIF.

We want to investigate the performance (both PSNR and coding time) of a set of wavelet filters. Three test sets are used (videos with a constant GOP 15, a constant GOP of 3 and our adaptive coder (with an adaptive GOP structure)). The underlying architecture used is a Laptop, Intel Celeron processor (1.7 GHz) with 1024 MB RAM. 5/3 defines the Daubechies-5/3-Wavelet, 9/7 the Daubechies-9/7-Wavelet and "both" results using both filters (Average PSNR in db, Coding time results in seconds). Coding with Haar defines coding in two ways: First Coding with only Haar wavelets (named "Haar-Haar") for the differential frame and the intra frame and secondly, coding with coding the intra frames with the 9/7 and the differential frame with the Haar wavelet (9/7 Haar). "bothcGOP15" and "bothcGOP3" define the usage of the 9/7 and the 5/3 filter (9/7 for intraframe and 5/3 for differential frame) for a constant GOP size of 15 respectively 3. "bothdyncoder" defines the filter for the intraframes and the usage of the 9/7 and the 5/3 filter (9/7 for intraframe and 5/3 for differential frame) for our adaptive coder.

Results for the quality performance are presented in Tables (1, 2, 3, 4, 5, 6, 7, 8). In most cases (Tables 4, 5, 6, 8) the combination of 9/7 and 9/7 for both intra and differential frame yields the best results (up to 0.6 db compared to the both case). In most of these scenarios the combination of 9/7 and 5/3 performs second best, followed by the 5/3 combination and the Haar. However, for some video sequences (Tables 1 2, 3, 7), the coding with the Haar wavelet (HaarHaar) (for both intra and differential frame) is yielding the similar results compared to coding with the "9/7 Haar" combination. We examine this result in more detail.

In Figure 2 the coding of the Haar combination and the 9/7 Haar combination is shown for the Foreman sequence. It shows for a constant GOP15 scenario that the "9/7-Haar" coding performing slightly better compared to the "Haar-Haar" case. The average PSNR difference between these two modi is 0.2 db. The difference between the "9/7-5/3" and the "9/7-9/7" case is 0.28 db.

Frame results show the difference of coding the differential frames (Refer to Figure 2. In addition, coding time using these filters has to be examined (Please refer to Table 9). On average the 9/7 combination is the mode with the highest computational demand, whereas the coding with only the Haar is the fastest.

Akiyo					
PSNR-Rate	20	50	100	150	200
both cGOP15	41.89	38.53	35.41	32.54	29.9
9/7	**42.16**	**38.75**	**35.61**	**32.74**	**30.07**
5/3	41.91	38.56	35.39	32.53	29.89
HaarHaar	41.88	38.49	35.37	32.53	29.87
9/7 Haar	41.68	38.26	35.19	32.34	29.72
both dyncoder	42.08	38.69	35.55	32.66	30.01
9/7	**42.32**	**38.87**	**35.74**	**32.84**	**30.18**
5/3	42.06	38.62	35.53	32.65	30
HaarHaar	42.05	38.62	35.52	32.63	29.98
9/7 Haar	41.82	38.44	35.32	32.46	29.83
both cGOP3	41.52	38.15	35.06	32.22	29.61
9/7	**41.75**	**38.37**	**35.26**	**32.41**	**29.78**
5/3	41.5	38.16	35.07	32.21	29.6
HaarHaar	41.48	38.12	35.03	32.19	29.59
9/7 Haar	41.29	37.92	34.85	32.03	29.44

Table 1. Average PSNR performance for Akiyo sequence for compression rates 20,50,100,150,200

Akiyo					
PSNR-Rate	20	50	100	150	200
both cGOP15	41.89	38.53	35.41	32.54	29.9
9/7	**42.16**	**38.75**	**35.61**	**32.74**	**30.07**
5/3	41.91	38.56	35.39	32.53	29.89
HaarHaar	41.88	38.49	35.37	32.53	29.87
9/7 Haar	41.68	38.26	35.19	32.34	29.72
both dyncoder	42.08	38.69	35.55	32.66	30.01
9/7	**42.32**	**38.87**	**35.74**	**32.84**	**30.18**
5/3	42.06	38.62	35.53	32.65	30
HaarHaar	42.05	38.62	35.52	32.63	29.98
9/7 Haar	41.82	38.44	35.32	32.46	29.83
both cGOP3	41.52	38.15	35.06	32.22	29.61
9/7	**41.75**	**38.37**	**35.26**	**32.41**	**29.78**
5/3	41.5	38.16	35.07	32.21	29.6
HaarHaar	41.48	38.12	35.03	32.19	29.59
9/7 Haar	41.29	37.92	34.85	32.03	29.44

Table 2. Average PSNR performance for Carphone sequence for compression rates 20,50,100,150,200

Claire					
PSNR-Rate	20	50	100	150	200
both cGOP15	29.71	26.7	24.27	22.33	21.88
9/7	**29.9**	**26.86**	**24.42**	**22.47**	**22.02**
5/3	29.64	26.63	24.21	22.27	21.83
HaarHaar	29.4	26.41	24.01	22.09	21.65
9/7 Haar	29.52	26.52	24.11	22.18	21.74
both dyncoder	29.12	26.17	23.81	21.88	21.45
9/7	**29.3**	**26.33**	**23.93**	**22.02**	**21.58**
5/3	29.05	26.1	23.74	21.83	21.39
HaarHaar	28.81	25.89	23.53	21.65	21.22
9/7 Haar	28.93	25.99	23.61	21.74	21.3
both cGOP3	29.71	26.7	24.21	22.33	21.88
9/7	**29.9**	**26.86**	**24.42**	**22.47**	**22.02**
5/3	29.64	26.63	24.18	22.27	21.83
HaarHaar	29.4	26.41	24.06	22.09	21.65
9/7 Haar	29.52	26.52	24.19	22.18	21.74

Table 3. Average PSNR performance for Claire sequence for compression rates 20,50,100,150,200

COASTGUARD					
PSNR-Rate	20	50	100	150	200
both cGOP15	30.96	27.52	25.65	24.59	23.93
9/7	**31.39**	**27.86**	**25.89**	**24.82**	**24.14**
5/3	30.86	27.44	25.52	24.59	23.91
HaarHaar	29.36	27.01	25.1	24.26	23.38
9/7 Haar	29.76	27.56	25.36	24.36	23.57
both dyncoder	32.42	28.11	25.83	24.67	23.87
9/7	**32.73**	**28.37**	**26.09**	**24.92**	**24.13**
5/3	32.14	27.87	25.72	24.63	23.92
HaarHaar	31.89	26.68	25.48	24.32	23.31
9/7 Haar	32.43	27.97	25.11	24.46	23.42
both cGOP3	32.33	28.19	25.91	24.73	23.96
9/7	**32.62**	**28.45**	**26.15**	**24.97**	**24.14**
5/3	32.10	28.00	25.74	24.72	23.95
HaarHaar	31.76	26.77	25.29	24.48	23.47
9/7 Haar	32.01	27.87	25.71	24.62	24.62

Table 4. Average PSNR performance for Coastguard sequence for compression rates 20,50,100,150,200

Foreman					
PSNR-Rate	20	50	100	150	200
both cGOP15	37.44	34.44	31.69	29.15	26.82
9/7	**37.79**	**34.74**	**31.99**	**29.43**	**27.07**
5/3	37.33	34.34	31.62	29.07	26.74
HaarHaar	36.71	33.73	31.02	28.51	26.3
9/7 Haar	36.71	33.77	31.07	28.59	26.3
both dyncoder	36.59	33.67	30.97	28.5	26.22
9/7	**36.91**	**33.95**	**31.24**	**28.74**	**26.44**
5/3	36.3	33.4	30.73	28.27	26.01
HaarHaar	36.29	33.32	30.72	28.23	25.99
9/7 Haar	36.14	33.25	30.53	28.14	25.89
both cGOP3	37.61	34.6	31.83	29.29	26.94
9/7	**37.93**	**34.9**	**32.1**	**29.54**	**27.17**
5/3	37.31	34.33	31.58	29.05	26.73
HaarHaar	37.29	34.31	31.53	29.04	26.71
9/7 Haar	37.14	34.17	31.44	28.92	26.61

Table 5. Average PSNR performance for Foreman sequence for compression rates 20,50,100,150,200

Garden					
PSNR-Rate	20	50	100	150	200
both cGOP15	27.2	23.66	20.59	17.91	15.58
9/7	**27.32**	**23.77**	**20.68**	**17.99**	**15.65**
5/3	27.29	23.74	20.66	17.97	15.63
HaarHaar	27.27	23.72	20.64	17.96	15.62
9/7 Haar	26.71	23.24	20.22	17.59	15.3
both dyncoder	27.37	23.81	20.72	18.02	15.68
9/7	**27.41**	**23.85**	**20.75**	**18.05**	**15.7**
5/3	27.34	23.79	20.69	18.03	15.66
HaarHaar	27.36	23.8	20.71	18.02	15.68
9/7 Haar	26.78	23.3	20.27	17.63	15.34
both cGOP3	27.29	23.74	20.66	17.97	15.63
9/7	**27.33**	**23.78**	**20.69**	**18**	**15.66**
5/3	27.26	23.72	20.63	17.95	15.62
HaarHaar	27.28	23.73	20.65	17.96	15.63
9/7 Haar	26.7	23.23	20.21	17.58	15.3

Table 6. Average PSNR performance for Garden sequence for compression rates 20,50,100,150,200

Grandma					
PSNR-Rate	20	50	100	150	200
both cGOP15	31.52	28.97	26.62	24.46	22.48
9/7	**31.7**	**29.13**	**26.77**	**24.6**	**22.61**
5/3	31.51	28.98	26.61	24.46	22.48
HaarHaar	31.49	28.94	26.6	24.46	22.46
9/7 Haar	31.33	28.77	26.46	24.32	22.35
both dyncoder	31.64	29.07	26.72	24.55	22.57
9/7	**31.82**	**29.24**	**26.87**	**24.7**	**22.69**
5/3	31.63	29.06	26.71	24.55	22.56
HaarHaar	31.61	29.04	26.69	24.53	22.54
9/7 Haar	31.45	28.9	26.56	24.41	22.43
both cGOP3	31.22	28.69	26.36	24.23	22.27
9/7	**31.39**	**28.85**	**26.51**	**24.37**	**22.39**
5/3	31.21	28.69	26.37	24.22	22.26
HaarHaar	31.19	28.66	26.34	24.21	22.24
9/7 Haar	31.03	28.52	26.21	24.08	22.13

Table 7. Average PSNR performance for Grandma sequence for compression rates 20,50,100,150,200

PARIS					
PSNR-Rate	20	50	100	150	200
both cGOP15	30.03	29.49	28.96	28.44	27.93
9/7	**30.15**	**29.61**	**29.07**	**28.55**	**28.04**
5/3	30.02	29.48	28.95	28.43	27.92
HaarHaar	29.97	29.43	28.9	28.38	27.87
9/7 Haar	29.69	29.16	28.63	28.12	27.61
both dyncoder	30.99	30.43	29.88	29.35	28.82
9/7	**31.12**	**30.56**	**30.01**	**29.47**	**28.94**
5/3	30.9	30.34	29.79	29.26	28.73
HaarHaar	30.89	30.33	29.78	29.25	28.72
9/7 Haar	30.69	30.14	29.59	29.06	28.54
both cGOP3	29.97	29.43	28.9	28.38	27.87
9/7	**30.1**	**29.56**	**29.03**	**28.5**	**27.99**
5/3	29.88	29.34	28.81	28.3	27.79
HaarHaar	29.87	29.33	28.8	28.29	27.78
9/7 Haar	29.68	29.15	28.62	28.11	27.6

Table 8. Average PSNR performance for Paris sequence for compression rates 20,50,100,150,200

Average					
Time-Rate	20	50	100	150	200
both cGOP15	52.29	51.30	49.65	50.91	49.12
9/7	52.87	52.56	51.59	51.54	51.78
5/3	50.17	51.23	49.47	49.17	49.65
HaarHaar	**49.06**	**48.56**	**48.27**	**48.38**	**48.96**
9/7 Haar	50.57	51.84	49.97	48.38	50.33
both dyncoder	41.22	41.11	40.54	40.87	40.40
9/7	42.87	42.77	42.01	42.11	41.93
5/3	40.66	41.23	40.15	40.32	39.84
HaarHaar	**40.12**	**39.42**	**38.43**	**38.61**	**38.73**
9/7 Haar	42.34	41.12	40.33	40.45	40.51
both cGOP3	41.86	41.35	40.73	40.9	40.42
9/7	43.06	43.05	42.19	42.32	41.98
5/3	40.93	41.30	40.11	40.52	39.84
HaarHaar	**40.82**	**39.45**	**38.61**	**38.85**	**39.07**
9/7 Haar	42.52	42.13	41.87	40.66	39.89

Table 9. Average coding time performance for all sequences for compression rates 20,50,100,150,200

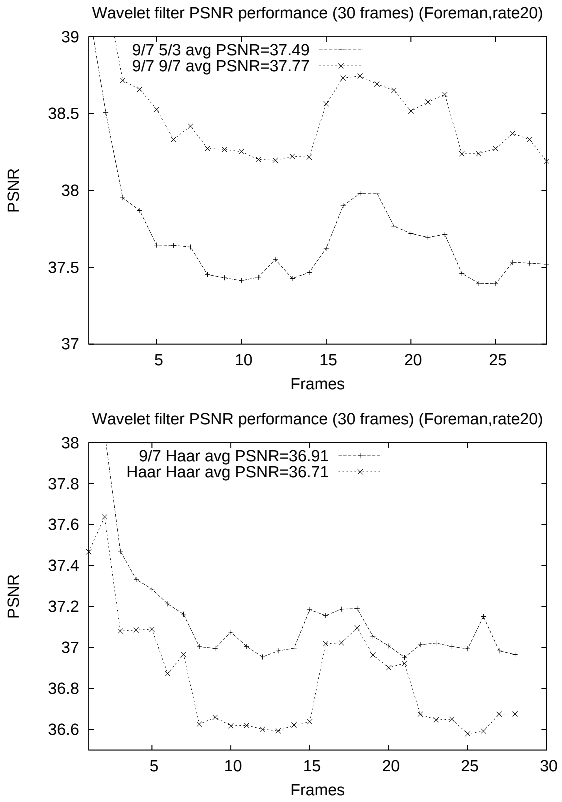
4.2 Hardware

The next investigation is concerned with the usage of the wavelet filters on hardware, which we already introduced in section 3. Both intra frames as well as differential frames could be coded using different wavelet filters. The lossless Daubechies-9/7-Wavelet (marked as 5/3) as well as the lossy Cohen-Daubechies-Feauveau-9/7 Wavelet (marked as 9/7) can be used in the hardware process. The coding with all the combinations of the filters did not show a significant difference in performance (up to 1%) because is all done in hardware.

5 Conclusion

In this paper we presented a evaluation of various wavelet filters for an adaptive interframe based video coder on software side as well on hardware side. The performance (coding time and image quality) of those filters (Wavelet filter 9/7 and 5/3, Haar) were examined. On software side, the combination of the 9/7 wavelet filters yielded slightly higher average image quality (PSNR) (up to 0.2-0.5 db), compared to the coding with just 5/3 filters. In addition, it was exhibited that coding with 9/7 filters leads to a higher computational load (as it was exspected).

Figure 2. Wavelet filters Detailed results - Foreman compression rate: 20



Furthermore, combining those filters on hardware side (5/3 for differential frames and 9/7 for intra frames) led to no improvement of performance (see ”Hardware Experiments”). By using our JPEG 2000 chip with full capacity, the whole system is predestined for High Definition as well as low bitrate scenarios.

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