

**ROBUST AND IMPERCEPTIBLE DIGITAL VIDEO
WATERMARKING TECHNIQUES**

SADIK ALI MURSHID AL-TAWEEL

UNIVERSITI SAINS MALAYSIA

2011

**ROBUST AND IMPERCEPTIBLE DIGITAL VIDEO
WATERMARKING TECHNIQUES**

by

SADIK ALI MURSHID AL-TAWEEL

**Thesis submitted in fulfilment of the requirements
for the degree of
Doctor of Philosophy**

February 2011

ACKNOWLEDGEMENTS

Although this thesis represents an achievement that bears my name, it would not have been possible without help of others whom I would like to thank. First, and for most, I thank Allah (SWT) for all his blessings and guidance.

I would like to express my sincere thanks and deepest gratefulness to my supervisor Assoc. Prof. Dr. Putra Sumari for his supervision, encouragements, guidance, insightful criticism, and for all of his help during my research work and preparation for this thesis. I would also seize this opportunity to express my special thanks to the School of Computer Sciences, USM, for all the facilities and support in this research.

I am also grateful to my parents for being there for me, and I dedicate this work to the soul of my father who waited long for this day to come and Almighty Allah (SWT) chose him to be closer to his mercy and blessings.

And last, but not least I am deeply grateful to my wife, for her prayers, love and care for her support and encouragement, and my kids for the time deducted from theirs to give me a time to finish this thesis.

TABLE OF CONTENTS

Acknowledgements.....	ii
Table of Contents.....	iii
List of Tables.....	x
List of Figures.....	xii
List of Abbreviations.....	xxiii
Abstrak.....	xxv
Abstract.....	xxvii
CHAPTER 1 – INTRODUCTION	
1.1 Digital Watermarking.....	2
1.2 Watermarking Objectives and Requirements.....	5
1.2.1 Robustness.....	5
1.2.2 Imperceptibility.....	5
1.2.3 Capacity.....	6
1.2.4 Security.....	6
1.2.5 Low Cost.....	7
1.3 Watermark Attacks.....	7
1.3.1 Geometric Attacks.....	7
1.3.2 Lossy Compression attack.....	8
1.3.3 Image processing attack.....	8
1.3.4 Noise attack.....	8
1.4 Research Motivation.....	9
1.5 Problem Statement.....	10
1.6 Objectives of the Thesis.....	11
1.7 Scope and Limitation.....	11
1.8 Research Approach.....	12

1.8.1	Problem Identification	13
1.8.2	Analysis of Current Techniques.....	13
1.8.3	Algorithm Design.....	13
1.8.4	Implementation	14
1.8.5	Evaluation.....	14
1.9	Thesis Contributions	15
1.10	Thesis organisation	15

CHAPTER 2 – BACKGROUND

2.1	Introduction	17
2.2	Watermarking Terminology	17
2.3	Basic Watermarking Schemes.....	18
2.4	Transform Techniques (DCT and DWT)	21
2.5	Spread Spectrum	26
2.6	Spatial Domain.....	26
2.7	Types of Attacks on Watermarks.....	28
2.7.1	Filtering and Noise addition.....	29
2.7.2	Scaling	29
2.7.3	Rotation	30
2.7.4	Cropping	31
2.7.5	Dropping	31
2.8	Pseudo-random number generators	31
2.9	MPEG-2 video	34
2.10	Chapter Summary	35

CHAPTER 3 – LITERATURE REVIEW

3.1	Introduction	36
3.2	Watermark Classification	36

3.3	Spread Spectrum watermarking (SS)	37
3.4	DCT domain Watermarking	39
3.4.1	Compressed domain MPEG-2 video	40
3.4.2	3D-DCT	41
3.4.3	Others	42
3.5	DWT domain Watermarking	42
3.5.1	1D-DWT	43
3.5.2	2D-DWT	44
3.5.3	3D-DWT	44
3.5.4	Other DWT techniques	48
3.6	Spatial domain Watermarking	48
3.7	Other transformation domains.....	53
3.7.1	DFT domain watermarking	53
3.7.2	Steerable pyramid technique	55
3.8	Discussion.....	56
3.9	Chapter Summary.....	59

CHAPTER 4 – FREQUENCY DOMAIN SPREAD SPECTRUM
WATERMARKING SCHEME

4.1	Introduction.....	61
4.2	Frequency domain of spread spectrum watermarking scheme.....	61
4.3	Watermark Generation	62
4.4	Watermark Embedding.....	66
4.4.1	SSDCT based embedding scheme	66
4.4.2	SSDWT based embedding scheme	68
4.5	Watermark Extraction.....	70
4.6	Performance Evaluation	73
4.6.1	Imperceptibility Result	74

4.6.1(a)	SSDCT	74
4.6.1(b)	SSDWT	75
4.6.2	Robustness of the Results of SSDCT and SSDWT	79
4.6.2(a)	Downscaling	79
4.6.2(b)	Cropping	80
4.6.2(c)	Rotation	81
4.6.2(d)	JPEG Compression	82
4.6.2(e)	Low Pass Filtering	84
4.6.2(f)	Median Filtering	85
4.6.2(g)	Wiener Filtering	86
4.6.2(h)	Gaussian Noise	87
4.6.2(i)	Salt and Pepper Noise	88
4.6.3	Performance Comparison.....	88
4.6.3(a)	SSDCT	89
4.6.3(b)	SSDWT	89
4.6.4	Discussion	90
4.7	Chapter Summary	98
CHAPTER 5 – 3D WAVELET-BASED WATERMARKING SCHEME		
5.1	Introduction	99
5.2	3D Wavelet-based watermarking scheme (3DDWT).....	99
5.3	Generation of the secret key	100
5.4	Watermark Modulation	101
5.5	Wavelet-based Watermark Embedding Process	102
5.5.1	Selection of Perceptual Significant Coefficients	104
5.5.2	Selection of Adaptive Scalars	105
5.5.3	Watermark Extraction Process	105
5.6	Robustness against Frame Dropping	106

5.6.1	Embedding Watermark	107
5.6.2	Watermark Extraction	108
5.7	Performance Evaluation	109
5.7.1	Imperceptibility Results	111
5.7.2	Robustness Results	112
5.7.2(a)	Downscaling	113
5.7.2(b)	Cropping	114
5.7.2(c)	Rotation.	115
5.7.2(d)	Frame Dropping	117
5.7.2(e)	JPEG compression.....	119
5.7.2(f)	Low pass filtering.....	120
5.7.2(g)	Median filtering.....	121
5.7.2(h)	Wiener filtering	122
5.7.2(i)	Gaussian noise	123
5.7.2(j)	Salt and Pepper Noise	124
5.8	Performance Comparison.....	125
5.9	Discussion.....	125
5.10	Summary	128
CHAPTER 6 – ROBUST SPATIAL WATERMARKING SCHEME		
6.1	Introduction	129
6.2	Robust spatial watermarking scheme (RSS).....	129
6.2.1	Watermark Modulation	130
6.2.2	Watermark Embedding Process	131
6.2.3	Robustness against Frame Dropping	132
6.2.4	Watermark Extraction	132
6.3	Performance evaluation.....	133
6.3.1	Imperceptibility Results	133

6.3.2	Robustness Results	134
6.3.2(a)	Downscaling	135
6.3.2(b)	Cropping	135
6.3.2(c)	Rotation	136
6.3.2(d)	Frame Dropping	137
6.3.2(e)	JPEG Compression	137
6.3.2(f)	Low Pass Filtering	138
6.3.2(g)	Median Filtering	139
6.3.2(h)	Weiner Filtering.....	140
6.3.2(i)	Gaussian Noise	140
6.3.2(j)	Salt and Pepper Noise	141
6.4	Performance Comparison.....	142
6.5	Discussion.....	143
6.6	Summary	144

CHAPTER 7 – THE OVERALL PERFORMANCE COMPARISON

7.1	Introduction	146
7.2	Experiment Setup	146
7.3	Imperceptibility	147
7.3.1	The Simulation Results of Performance Measurement	147
7.4	Robustness	149
7.4.1	Geometric Attack	150
7.4.2	Image processing attack.....	152
7.4.3	Noise Attack	154
7.4.4	JPEG Compressions	156
7.5	Discussion.....	157
7.6	Chapter Summary.....	161

CHAPTER 8 – CONCLUSION AND FUTURE WORK	
8.1	Conclusion 163
8.2	Future Work 166
	References 167
APPENDICES 173	
APPENDIX A – FREQUENCY DOMAIN SPREAD SPECTRUM WATERMARKING SCHEME	..... 174
APPENDIX B – 3D-WAVELET-BASED WATERMARKING ALGORITHM (3DDWT)	..... 178
APPENDIX C – ROBUST SPATIAL WATERMARKING SCHEME (RSS)	..... 180
APPENDIX D – THE OVERALL PERFORMANCE COMPARISON	..... 182
List of Publications	..... 186

LIST OF TABLES

		Page
Table 2.1	Types of attacks on watermarks	28
Table 2.2	Difference between picture types	35
Table 3.1	The summary of DCT research results in video watermarking	43
Table 3.2	The summary of DWT research results in video watermarking	49
Table 3.3	Summary of spatial domain research results in video watermarking	54
Table 5.1	Video clips used in testing	109
Table 6.1	Video clips used in testing	133
Table 7.1	Video clips used in testing	147
Table 7.2	A summary of the performance of the watermarking methods	162
Table A.1	A summary of the performance of the original spread algorithm.	175
Table A.2	A summary of the performance of SSDCT.	176
Table A.3	A summary of the performances of SSDWT	177
Table B.1	A summary of the performance of 3DDWT algorithm	179
Table C.1	A summary of the performance of RSS watermarking algorithm	181
Table D.1	A summary of the Robustness against Scaling down attack	182
Table D.2	A summary of the Robustness against Cropping attack	182
Table D.3	A summary of the Robustness against Low-pass filtering attack	182
Table D.4	A summary of the Robustness against Median filtering attack	183
Table D.5	A summary of the Robustness against Wiener filtering attack	183
Table D.6	A summary of the Robustness against Gaussian Noise attack	183
Table D.7	A summary of the Robustness against Salt & Pepper Noise attack	183

Table D.8	A summary of the Robustness against JPEG Compression attack	184
Table D.9	A summary of the Robustness against Rotation attack	185

LIST OF FIGURES

		Page
Figure 1.1	Losses of Copyright Piracy 2009	2
Figure 1.2	Types of watermark	3
Figure 1.2(a)	Visible watermark	3
Figure 1.2(b)	Invisible watermark.....	3
Figure 1.3	Elements which will be protected by copyright protection	4
Figure 1.4	Research Approach	12
Figure 2.1	The generic watermark embedding process	18
Figure 2.2	The generic watermark recovery process	19
Figure 2.3	Experimental Detection	20
Figure 2.4	DWT for two dimensional images.	24
Figure 2.5	The pyramidal two-level decomposition of an image.	25
Figure 2.5(a)	Original frame	25
Figure 2.5(b)	Watermarked frame.....	25
Figure 2.6	Energy distribution in the transform domain.	26
Figure 2.6(a)	DCT	26
Figure 2.6(b)	DWT	26
Figure 2.7	Methods of Subsampling (a) Replacement with Upper-left pixel (b) Interpolation using the mean.	30
Figure 2.8	Methods of Zooming (a) Replication of a single pixel value (b) Interpolation.	30
Figure 2.9	Types of picture of the MPEG-2 video.	35
Figure 3.1	Classification of watermarking schemes	37
Figure 3.2	Block diagram of steerable pyramid decomposition	56
Figure 4.1	Model of watermarking	62

Figure 4.2	Watermark model using SSDCT algorithm	63
Figure 4.3	Watermark model using SSDWT algorithm	64
Figure 4.4	Spreading using chip rate	64
Figure 4.5	Random sequence generator	66
Figure 4.6	Watermark embedding process in DCT domain	67
Figure 4.7	Watermark embedding process in DWT domain	71
Figure 4.8	Watermark extraction model	72
Figure 4.9	Model of watermarking attacks	74
Figure 4.10	(a) Original and (b) Watermarked frames of "Susi on the phone"	75
Figure 4.10(a)	.....	75
Figure 4.10(b)	.....	75
Figure 4.11	(a) Original and (b) Watermarked frames of "Flower"	75
Figure 4.11(a)	.....	75
Figure 4.11(b)	.....	75
Figure 4.12	(a) Original and (b) Watermarked frames of "Football"	75
Figure 4.12(a)	.....	75
Figure 4.12(b)	.....	75
Figure 4.13	(a) Original and (b) Watermarked frames of "Mobile"	76
Figure 4.13(a)	.....	76
Figure 4.13(b)	.....	76
Figure 4.14	(a) Original and (b) Watermarked frames of "Tempt"	76
Figure 4.14(a)	.....	76
Figure 4.14(b)	.....	76
Figure 4.15	(a) Original and (b) Watermarked frames of "Tennis"	76
Figure 4.15(a)	.....	76
Figure 4.15(b)	.....	76
Figure 4.16	The USM Logo used as a watermark	76
Figure 4.17	(a) Original and (b) Watermarked frames of "Susi on the phone"	77

Figure 4.17(a)	.....	77
Figure 4.17(b)	.....	77
Figure 4.18	(a) Original and (b) Watermarked frames of "Flower"	77
Figure 4.18(a)	.....	77
Figure 4.18(b)	.....	77
Figure 4.19	(a) Original and (b) Watermarked frames of "Football"	77
Figure 4.19(a)	.....	77
Figure 4.19(b)	.....	77
Figure 4.20	(a) Original and (b) Watermarked frames of "Mobile"	78
Figure 4.20(a)	.....	78
Figure 4.20(b)	.....	78
Figure 4.21	(a) Original and (b) Watermarked frames of "Tempete"	78
Figure 4.21(a)	.....	78
Figure 4.21(b)	.....	78
Figure 4.22	(a) Original and (b) Watermarked frames of "Tennis"	78
Figure 4.22(a)	.....	78
Figure 4.22(b)	.....	78
Figure 4.23	Results of random watermark detection under scaling down attack for (a) SSDCT and (b) SSDWT	80
Figure 4.23(a)	.....	80
Figure 4.23(b)	.....	80
Figure 4.24	Results of random watermark detection under cropping attack for (a) SSDCT and (b) SSDWT	81
Figure 4.24(a)	.....	81
Figure 4.24(b)	.....	81
Figure 4.25	Results of random watermark detection under rotation attack for (a) SSDCT and (b) SSDWT	81
Figure 4.25(a)	.....	81
Figure 4.25(b)	.....	81

Figure 4.26	Results of random watermark detection under JPEG 100% quality parameter attack for (a) SSDCT and (b) SSDWT	82
Figure 4.26(a)	.....	82
Figure 4.26(b)	.....	82
Figure 4.27	Results of random watermark detection under JPEG 75% quality parameter attack for (a) SSDCT and (b) SSDWT	83
Figure 4.27(a)	.....	83
Figure 4.27(b)	.....	83
Figure 4.28	Results of random watermark detection under JPEG 50% quality parameter attack for (a) SSDCT and (b) SSDWT	83
Figure 4.28(a)	.....	83
Figure 4.28(b)	.....	83
Figure 4.29	Results of random watermark detection under JPEG 25% quality parameter attack for (a) SSDCT and (b) SSDWT	84
Figure 4.29(a)	.....	84
Figure 4.29(b)	.....	84
Figure 4.30	Results of random watermark detection under low pass filtering attack for (a) SSDCT and (b) SSDWT	85
Figure 4.30(a)	.....	85
Figure 4.30(b)	.....	85
Figure 4.31	Results of random Watermark detection under median filtering attack for (a) SSDCT and (b) SSDWT	86
Figure 4.31(a)	.....	86
Figure 4.31(b)	.....	86
Figure 4.32	Results of random Watermark detection under Wiener filtering attack for (a) SSDCT and (b) SSDWT	86
Figure 4.32(a)	.....	86
Figure 4.32(b)	.....	86
Figure 4.33	Results of random Watermark detection under Gaussian noise attack for (a) SSDCT and (b) SSDWT	87
Figure 4.33(a)	.....	87

Figure 4.33(b)	.....	87
Figure 4.34	Results of random Watermark detection under salt and pepper noise attack for (a) SSDCT and (b) SSDWT	88
Figure 4.34(a)	.....	88
Figure 4.34(b)	.....	88
Figure 4.35	Robustness of the SSDCT algorithm	89
Figure 4.36	Robustness of the SSDWT algorithm	90
Figure 4.37	Watermarked frame after JPEG compression with 100% quality for (a) SSDCT and (b) SSDWT.	91
Figure 4.37(a)	.....	91
Figure 4.37(b)	.....	91
Figure 4.38	Watermarked frame after JPEG compression with 75% quality for (a) SSDCT and (b) SSDWT.	91
Figure 4.38(a)	.....	91
Figure 4.38(b)	.....	91
Figure 4.39	Watermarked frame after JPEG compression with 50% quality for (a) SSDCT and (b) SSDWT.	92
Figure 4.39(a)	.....	92
Figure 4.39(b)	.....	92
Figure 4.40	Watermarked frame after JPEG compression with 25% quality for (a) SSDCT and (b) SSDWT.	92
Figure 4.40(a)	.....	92
Figure 4.40(b)	.....	92
Figure 4.41	Robustness of original, SSDCT and SSDWT algorithms against JPEG compression	92
Figure 4.42	Watermarked frame after low pass filtering for (a) SSDCT and (b) SSDWT	93
Figure 4.42(a)	.....	93
Figure 4.42(b)	.....	93
Figure 4.43	Watermarked frame after median filtering for (a) SSDCT and (b) SSDWT	93

Figure 4.43(a)	.....	93
Figure 4.43(b)	.....	93
Figure 4.44	Watermarked frame Wiener filtering for (a) SSDCT and (b) SSDWT	93
Figure 4.44(a)	.....	93
Figure 4.44(b)	.....	93
Figure 4.45	Robustness of the original algorithm, SSDCT and SSDWT algorithms against low pass filtering.	94
Figure 4.46	Robustness of the original algorithm, SSDCT and SSDWT algorithms against median filtering.	94
Figure 4.47	Robustness of the original algorithm, SSDCT and SSDWT algorithms against Wiener filtering	94
Figure 4.48	Watermarked frame after downscaling for (a) SSDCT and (b) SSDWT	95
Figure 4.48(a)	.....	95
Figure 4.48(b)	.....	95
Figure 4.49	Watermarked frame after cropping for (a) SSDCT and (b) SSDWT	95
Figure 4.49(a)	.....	95
Figure 4.49(b)	.....	95
Figure 4.50	Watermarked frame after rotation for (a) SSDCT and (b) SSDWT	95
Figure 4.50(a)	.....	95
Figure 4.50(b)	.....	95
Figure 4.51	Robustness of the original, SSDCT and SSDWT algorithms against Downscaling	96
Figure 4.52	Robustness of the original, SSDCT and SSDWT algorithms against Cropping	96
Figure 4.53	Robustness of the original, SSDCT and SSDWT algorithms against Rotation	96
Figure 4.54	Watermarked frame after Gaussian noise for (a) SSDCT and (b) SSDWT	96
Figure 4.54(a)	.....	96
Figure 4.54(b)	.....	96

Figure 4.55	Watermarked frame after Salt and Pepper noise for (a) SSDCT and (b) SSDWT	97
Figure 4.55(a)	.....	97
Figure 4.55(b)	.....	97
Figure 4.56	Robustness of the original algorithm, SSDCT and SSDWT algorithms against Gaussian noise	97
Figure 4.57	Robustness of the original, SSDCT and SSDWT algorithms against salt and pepper noise	97
Figure 5.1	Model of 3DDWT watermarking scheme	100
Figure 5.2	Key Generation	101
Figure 5.3	Shift operation	101
Figure 5.4	Watermark embedding process	103
Figure 5.5	Watermark extraction process	106
Figure 5.6	Block diagram of the proposed method for frame dropping	107
Figure 5.7	Essential operation of embedding each block of watermark in scenes of video	108
Figure 5.8	Watermark Extraction algorithm	108
Figure 5.9	(a) The original frame of "Susi on the phone" (b) The watermarked frame of "Susi on the phone" (c) The extracted watermark	110
Figure 5.9(a)	.....	110
Figure 5.9(b)	.....	110
Figure 5.9(c)	.....	110
Figure 5.10	(a) The original frame of "Flower" (b) The watermarked frame of "Flower" (c) The extracted watermark	110
Figure 5.10(a)	.....	110
Figure 5.10(b)	.....	110
Figure 5.10(c)	.....	110
Figure 5.11	(a) The original frame of "Football" (b) The watermarked frame of "Football" (c) The extracted watermark	110
Figure 5.11(a)	.....	110

Figure 5.11(b)	.....	110
Figure 5.11(c)	.....	110
Figure 5.12	(a) The original frame of "Mobile"(b) The watermarked frame of "Mobile"(c) The extracted watermark	111
Figure 5.12(a)	.....	111
Figure 5.12(b)	.....	111
Figure 5.12(c)	.....	111
Figure 5.13	(a) The original frame of "Tempete" (b) The watermarked frame of "Tempete" (c) The extracted watermark	111
Figure 5.13(a)	.....	111
Figure 5.13(b)	.....	111
Figure 5.13(c)	.....	111
Figure 5.14	(a) The original frame of "Tennis" (b) The watermarked frame of "Tennis" (c) The extracted watermark	111
Figure 5.14(a)	.....	111
Figure 5.14(b)	.....	111
Figure 5.14(c)	.....	111
Figure 5.15	Watermark without any attack: (a) The original watermark, (b) The extracted watermark, and (c) Watermark detection results	112
Figure 5.15(a)	.....	112
Figure 5.15(b)	.....	112
Figure 5.15(c)	.....	112
Figure 5.16	Watermarked frame under downscaling attack	113
Figure 5.17	Extracted watermark under downscaling attack	113
Figure 5.18	Results of watermark detection under downscaling	114
Figure 5.19	Watermarked frame under cropping attack	114
Figure 5.20	Decoded watermark under cropping attack	115
Figure 5.21	Results of random watermark detection under cropping	115

Figure 5.22	Watermarked frame under rotation attack: (a) 5° clockwise (b) 10° clockwise (c) 15° clockwise (d) 30° clockwise (e) 5° anticlockwise (f) 10° anticlockwise (g) 15° anticlockwise, and (h) 30° anticlockwise	116
Figure 5.22(a)	.....	116
Figure 5.22(b)	.....	116
Figure 5.22(c)	.....	116
Figure 5.22(d)	.....	116
Figure 5.22(e)	.....	116
Figure 5.22(f)	.....	116
Figure 5.22(g)	.....	116
Figure 5.22(h)	.....	116
Figure 5.23	Watermarked frame under rotation attack	117
Figure 5.24	Decoded watermark under rotation attack	117
Figure 5.25	Results of random watermark detection under rotation	117
Figure 5.26	Frames on the scene boundaries of the video: "Susi on the phone", "Tennis", "Flower", and "Mobile".	118
Figure 5.27	Results of random watermark detection under frame dropping	118
Figure 5.28	Watermarked frame under JPEG compression attack	119
Figure 5.29	Extracted logo from frame under JPEG compression attack	119
Figure 5.30	Results of random watermark detection under JPEG compression attack	120
Figure 5.31	Watermarked frame under low pass filtering attack	120
Figure 5.32	Decoded watermark under low pass filtering attack	120
Figure 5.33	Results of random watermark detection under low pass filtering attack	121
Figure 5.34	Watermarked frame under median filtering attack	121
Figure 5.35	Decoded watermark under median filtering attack	121
Figure 5.36	Results of random watermark detection under median filtering attack	122
Figure 5.37	Watermarked frame under Wiener filtering attack	122
Figure 5.38	Decoded watermark under Wiener filtering attack	122
Figure 5.39	Results of random watermark detection under Wiener filtering attack	123

Figure 5.40	Watermarked frame under Gaussian noise attack	123
Figure 5.41	Decoded watermark under Gaussian noise attack	123
Figure 5.42	Results of random watermark detection under Gaussian noise attack	124
Figure 5.43	Watermarked frame under salt and pepper attack	124
Figure 5.44	Decoded watermark under salt and pepper attack	124
Figure 5.45	Results of random watermark detection under salt and pepper attack	125
Figure 5.46	Robustness of Proposed 3DDWT version algorithm	126
Figure 6.1	Model of RSS watermarking scheme	130
Figure 6.2	Modulation of the watermark	131
Figure 6.3	Original watermark logo	133
Figure 6.4	"Susi on the phone" (a) Original and (b)Watermarked frames.	134
Figure 6.4(a)	.....	134
Figure 6.4(b)	.....	134
Figure 6.5	Decoded watermark under scaling down attack	135
Figure 6.6	Results of random watermark detection under downscaling attack	135
Figure 6.7	Decoded watermark under cropping attack	136
Figure 6.8	Results of random watermark detection under cropping attack	136
Figure 6.9	Decoded watermark under rotation attack	136
Figure 6.10	Results of random watermark detection under rotation attack	136
Figure 6.11	Decoded watermark under frame dropping attack	137
Figure 6.12	Results of random watermark detection under frame dropping attack	137
Figure 6.13	Decoded watermark under JPEG attack	138
Figure 6.14	Results of random watermark detection under JPEG attack	138
Figure 6.15	Decoded watermark under low pass filtering attack	138
Figure 6.16	Results of random watermark detection under low pass filtering attack	139
Figure 6.17	Decoded watermark under median filtering attack	139
Figure 6.18	Results of random watermark detection under median filtering attack	139

Figure 6.19	Decoded watermark under Wiener filtering attack	140
Figure 6.20	Results of random watermark detection under Wiener filtering attack	140
Figure 6.21	Decoded watermark under Gaussian noise attack	141
Figure 6.22	Results of random watermark detection under Gaussian noise filtering attack	141
Figure 6.23	Decoded watermark under Salt and Pepper attack	141
Figure 6.24	Results of random watermark detection under Salt and Pepper attack	141
Figure 6.25	Robustness of the Proposed RSS algorithm	142
Figure 7.1	Quality of the watermarked video	148
Figure 7.2	Robustness against scaling down attack.	150
Figure 7.3	Robustness against cropping attack.	151
Figure 7.4	Robustness against rotation attack.	152
Figure 7.5	Robustness against low pass filtering attack.	152
Figure 7.6	Robustness against median filtering attack.	153
Figure 7.7	Robustness against Wiener filtering attack.	154
Figure 7.8	Robustness against Gaussian noise attack.	155
Figure 7.9	Robustness against Salt and Pepper noise attack.	155
Figure 7.10	Robustness against JPEG compression attack.	156

LIST OF ABBREVIATIONS

CMS Computer Mediated System

3D-DWT Three Dimensional Discrete Wavelet Transform

B0 Band-pass

B-pictures Bidirectionally-predictive pictures

CDMA Code-Division Multiple Access

CIF Common intermediate format

CR Collusion Resistant

Cr Chip- rate

DCT Discrete Cosine Transform

DFT Discrete Fourier Transform

DVD Digital Video Disc

DWT Discrete Wavelet Transform

FFT Fast Fourier Transform

GOP Group of pictures

H0 High-pass

HVS Human Visual System

IDWT Inverse Discrete Wavelet Transform

I-pictures Intra pictures

ISBN International Standard Book Number

ISRC International Standard Recording Code

JPEG Joint Photographic Experts Group

KD Key Detection

KE Key Embedded

L0 Low-pass

LSB Least Significant Bit

MPEG Moving Picture Experts Group

MRA Multi-resolution approximation

MRR Multi-resolution representation

MSE Mean square errors

NC Normalized correlation

NCC Normalized correlation coefficients

OEM Original equipment manufacturer

PN Pseudo-random noise

P-pictures Predictive pictures

PSNR Peak signal to noise ratio

PW Perceptual watermarking

RBEM Region Based Energy modification

SVD Singular Value Decomposition

TEKNIK PENANDAAN-AIR VIDEO DIGITAL YANG TEGUH DAN TIDAK BOLEH DITANGGAP

ABSTRAK

Pengeluaran bahan video dan imej yang banyak dalam sistem berperantaraan komputer di Internet telah memberikan cabaran besar dalam bidang perlindungan hak milik. Banyak cetakan yang tidak sah telah dibuat dan usaha untuk membuktikan perlindungan hak milik terpelihara terhadap bahan media berkenaan adalah satu tugas yang mencabar. Penandaan-air digital merupakan salah satu penyelesaian yang boleh membuktikan hak milik dengan cara membenamkan satu penanda (mengandungi maklumat pemilik) ke dalam imej atau video berkenaan. Penanda berkenaan akan digunakan sebagai bahan bukti terhadap usaha membuktikan tuntutan hak milik. Oleh sebab itu, penanda yang dibenamkan seharusnya teguh dan tidak boleh ditanggapi terhadap sebarang percubaan untuk membuang dan mengubahsuainya. Walau bagaimanapun, memastikan penanda berkenaan selamat daripada sebarang percubaan pengubahsuaian untuk tujuan mengekalkan keasliannya merupakan halangan utama dalam pembangunan sistem penandaan-air video digital. Penanda yang dibenamkan di dalam imej dan video mudah di terubahsuai hasil daripada kegiatan seperti manipulasi geometri, proses pemprosesan imej, proses pemampatan dan hingar. Ini (yang juga dipanggil serangan) telah menyebabkan penanda tersebut tidak lagi serupa dengan yang asli dan ini akan menggagalkan proses tuntutan hak milik. Kajian ini mempersembahkan empat teknik sistem penandaan-air yang teguh dan tidak boleh ditanggapi terhadap serangan. Skim pertama dipanggil domain frekuensi spektrum rebak. Skim ini menggunakan jujukan rebak modulasi dalam mewakili penanda. Dalam proses pembedaannya pula, dua domain proses pembedaan domain frekuensi dipanggil

transformasi kosain diskret spektrum rebak (SSDCT) dan transformasi wavelet spektrum rebak (SSDWT) dipersembahkan. Kedua-dua skim ini membenarkan penanda koefisien yang ditransformasikan ke dalam rangka terpilih yang mempunyai frekuensi tinggi. Skim ketiga dipanggil skim penandaan-air berasaskan wavelet 3-D. Skim ini mentransformasikan rangka kepada tiga paras dan bit penanda yang telah dimodulasikan dibenamkan ke dalam koefisien terisah yang tertinggi. Skim terakhir dipanggil skim penanda-air spatial teguh (RSS). Skim ini merupakan pendekatan domain spatial dengan penanda dalam bentuk bit pseudo-rawak dibenamkan ke dalam piksel menggunakan modulasi XOR secara bait. Pretasi skim diukur berdasarkan keteguhan dan kebolehtanggapan terhadap empat jenis serangan: serangan geometri, serangan pemprosesan imej, serangan pemampatan hilang dan serangan hingar. Keputusan menunjukkan bahawa skim-skim berkenaan menambah baik keteguhan dan keupayaan tidak boleh ditanggap terhadap empat jenis serangan tersebut dari segi PNSR dan korelasi yang baik berbanding dengan skim-skim lain yang serupa.

ROBUST AND IMPERCEPTIBLE DIGITAL VIDEO WATERMARKING TECHNIQUES

ABSTRACT

The massive production of image and video materials on the Computer Mediated Systems (CMS) over the Internet has created a challenge in the area of copyright protection. Numerous illegal copies have been made and efforts on proving the owner copyright of those media are indeed a challenging task. Digital watermarking is a solution that can be used to prove the ownership/copyright by embedding watermark (owner, information) into the image/video. Later, the embedded watermark is used as a proof and evidence for the real ownership. Thus, the embedded watermark should be robust and imperceptible against any attempt of removing and alteration on it. However, guaranteeing against any alteration as to preserve the originality is one of the major hurdles in image and video watermarking system. The embedded watermark in the image is easily distorted / altered from activities such as geometric manipulation, image processing process, compression process and noises within the image. Those (also being referred to as attacks) has caused the extracted watermark not similar to the original one and thus denying ownership claiming. This study presents four watermarking techniques that are robust and imperceptible against attacks. The first scheme is called Spread Spectrum Frequency Domain. This scheme uses modulated spread spectrum sequence in representing the watermark. In the embedding process, two frequency domain embedding process called Spread Spectrum Discrete Cosine transform (SSDCT) and Spread Spectrum Wavelet transform (SSDWT) are presented. Both schemes embedded the transformed coefficients watermark into the high frequency of transform coefficient of the selected frames. The third scheme is called 3-D wavelet

based watermarking scheme (3D-DWT). The scheme transforms the frame into three levels and the modulated watermark bits are embedded in the highest sorted coefficients. The final scheme is called Robust Spatial Watermarking Scheme (RSS). This is a spatial domain approach in which the watermark in the form of pseudo-random bit is embedded within pixels of selected frame using XOR bit wise modulation. The performance of the schemes is measured based on its robustness and imperceptibility against four types of attacks: geometric attack, image processing attack, lossy compression attack and noise attack. The results have shown that the schemes have improved the robustness and imperceptibility against those four types of attacks in term of good PNSR and correlation compared to other similar existing schemes.

CHAPTER 1

INTRODUCTION

Today, we see that multimedia data such as video, music, text, and image are growing at a very fast rate. One of the characteristics of these data is that they can be transferred and copied easily to any storage medium anyplace and anytime. This has raised many issues such as illegal copying and piracy. Japan ranks high among the countries dealing with illegal copying over the internet. The number of users of file-sharing software such as "Winny" is estimated to be about 1.75 million, with most of the files exchanged using illegal copies of the software (Cooper, 2008). A brief six-hour survey conducted by a copyright organization monitoring the Internet found approximately 3.55 million examples of illegally copied gaming software, worth about 9.5 billion yen, at standard software prices. Furthermore, 610,000 illegally copied music files worth 440 million yen could freely be downloaded into personal computers by means of such software. This survey alone, estimated damages worth 10 billion yen (Cooper, 2008). Another survey conducted by International Intellectual Property Alliance (Eric H. Smith, 2010) on the statistics of copyright piracy in 2009 of video in Argentina, Canada, Chile, Costa Rica, India, Indonesia, Mexico, Philippines, China, Russian, and Italy revealed the losses as shown in Figure(1.1) and estimated damages worth (1, 966, 6 billion USD) (Eric H. Smith, 2010; IIPA, 2009).

The motion picture industry has also been affected by the growing online piracy crisis. Approximately, 90% of the pirated DVDs and other optical media products sold by street vendors, or internet auction sites, originate either from illegal uploads by peer to peer networks (p2p) or from illegal imports. In spite of the criminal conviction of the developer of "Winny" p2p

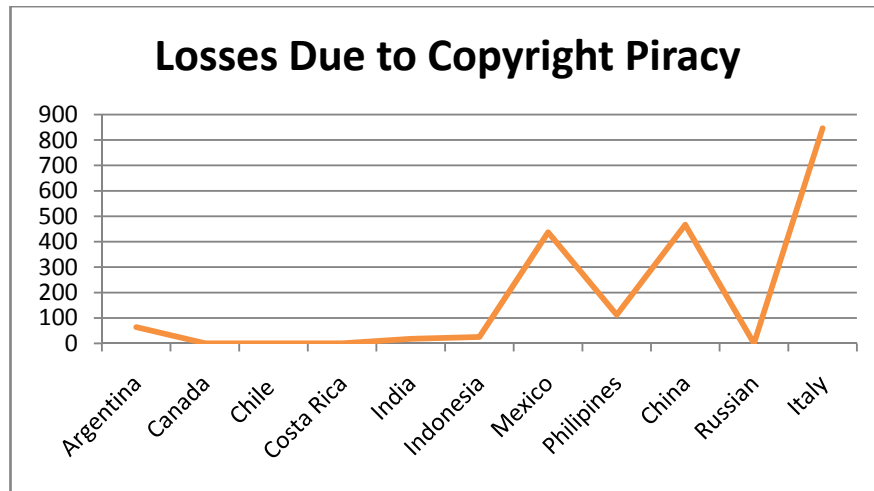


Figure 1.1: Losses of Copyright Piracy 2009 (Eric H. Smith, 2010)

file sharing system in 2006, it still remains in operation and is a source of online piracy (IIPA, 2009).

Digital watermarking has recently become a popular area of research due to the proliferation of digital data (image, audio, or video) on the internet and the need to find a way to protect the above issues. Numerous digital watermarking algorithms are also developed to help protect the copyright of digital video and to verify the multimedia data integrity (Liu and Zhao, 2009).

1.1 Digital Watermarking

Digital watermark is a signal (e.g. symbol, ownership information) that is securely, imperceptibly, and robustly embedded into innocent-looking host such as an image, a video, or an audio signal. The watermark can contain information that can be used for proof of ownership or tamper proving (Hussein, 2010). It is a one-to-many communication and the signal should be robust against an attempt on removing it (Aliwa et al., 2009).

Different watermarking applications exhibit different requirements such as fingerprinting, copy protection, data authentication and copyright protection. In case of fingerprinting, the copyholder (the seller of a digital data, for example) might also want to know which customer

has leaked an unauthorized copy of data. Here, fingerprinting and distribution tracking techniques are used to identify not only the seller but also the buyer of a digital data (Karzenbeisser and Perircolas, 2000). However, copy protection means disallowing unauthorized copying of digital data. In open systems like the Internet, it is very difficult to achieve copy protection but, it is possible to enforce copy protection in a controlled system like the DVD player (Meerwald, 2001; Loo and Kingsbury, 2000). The objective of authentication applications is to detect any modifications on the data (Fridrich, 1999; Kundur and Hatzinakos, 1998). Fragile watermarks can be used to check the authenticity of the data. If the data, for example, are modified maliciously, the watermark will be destroyed. If the watermark can be retrieved by the recipient, the data is considered to be authentic. Otherwise, it should be discarded.

The most popular application of watermarking is copyright protection, i.e., embedding copyright statements that prove the ownership of original data clearly. Digital watermarks can be visible and invisible. We see visible watermarks every day, such as tv station logos as shown in Figure 1.2a and we also see invisible watermarks in banknotes and passports. Figure 1.2b shows an invisible watermark of a banknote. The copyright information should resist any modifications and/or manipulations that may alter the original information (Loo and Kingsbury, 2000; Neil et al., 2000; Fu, 1998).



(a) Visible watermark



(b) Invisible watermark

Figure 1.2: Types of watermark

The owner of digital data can quickly extract the watermark in order to prove ownership (Meerwald, 2001). This will prevent other parties from claiming the copyright of the data. Thus, this application requires a very high level of robustness. Note that watermarks for copyright protection do not prevent any person from copying the digital data. They simply exist as a means for owners to declare ownership over some digital data (Karzenbeisser and Perircolas, 2000). In this case, the author or originator integrates a watermark with his own intellectual property signature into the original document and delivers it as usual. By doing this, he can prove his intellectual creation later on, for instance, in a legal proceeding and has the possibility to assert entitlement to the restricted use (Seitz, 2005).

Although, copyright legislation does not define digital materials (Multimedia or Websites) as separate categories, these media platforms comprise one or more elements which can be protected by copyright. These media platforms include digital images, digital sound recordings, films, digital broadcasts and e-books, which can be classified according to the existing definitions of works and are protected by copyright as shown in Figure 1.3.

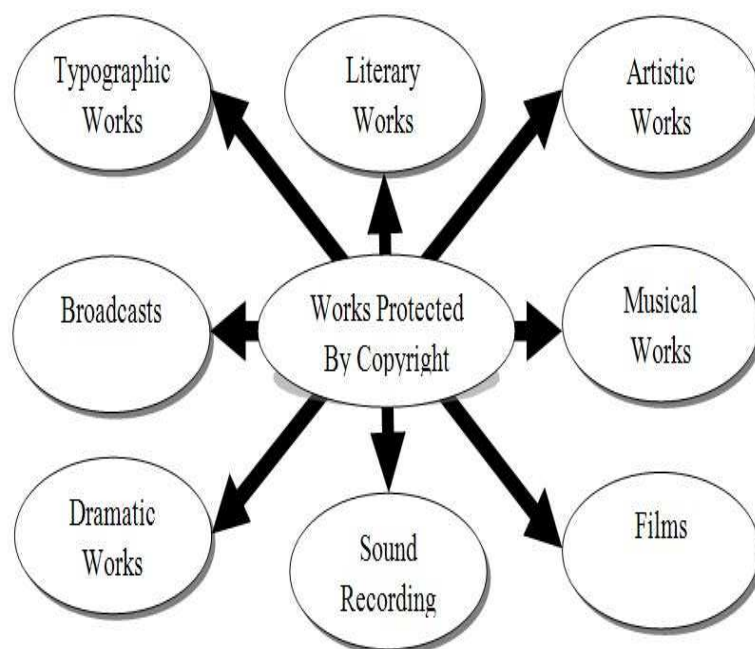


Figure 1.3: Elements which will be protected by copyright protection

A survey in October 2008 by IIPA (2009) indicated that nearly two-third of mobile phone users are in their early teens, and more than one-third of all the users are engaged in unauthorized music downloads. Unauthorized file sharing on PCs reached an estimated level of 84 million tracks in 2008, which outstripped the legal market nearly 2 to 1. It is encouraging that three arrests were made during October and November of 2008 of those operating, uploading, and hosting mobile music piracy sites, yet far greater efforts are required to save the market from being lost to piracy (IIPA, 2009).

1.2 Watermarking Objectives and Requirements

An effective watermark should have several properties whose importance varies depending on the application. These properties are described in the following subsections.

1.2.1 Robustness

Robustness here refers to the resistance of the watermarked message towards any form of malicious distortion which does not render the digital data useless. Robustness is the most fundamental for watermarking. The data after being embedded into cover-media, and after compression or other processing must also be recoverable from watermarking. It must be able to resist lossy data compression, filtering and other kinds of destruction without losing its function.

1.2.2 Imperceptibility

To conserve the quality of the marked document, the watermark should not obviously distort the original document. Ideally, the original and marked documents should be perceptually matching (Hartung et al., 1999). The embedded data should depend on the application and purpose of the watermarking system and should be minimally perceptible by the human visual or auditory systems (Bender et al., 1996).

Robustness and imperceptibility are the most important requirements for an effective watermarking system. Unfortunately, these requirements are in conflict and all watermarking algorithms involve determining a trade off between these two conflicting requirements. Using a good perceptual model will allow us to maximize the energy of watermark while keeping its visibility to a minimum (Busch et al., 1999; Sowers and Yousef, 1998).

1.2.3 Capacity

Capacity refers to the maximum amount or size of the information that can be embedded in a cover-media. A capacity of one bit (one = allow/zero = reject) seems to be sufficient in digital watermarking for simple copy control applications. For example, intellectual property applications require at least 60 to 70 bits information capacity to embed data about copyright, authors, limitations, International Standard Recording Code (ISRC), or International Standard Book Number (ISBN), or original equipment manufacturer (OEM) and other information (Seitz, 2005).

1.2.4 Security

The attacker is supposed to have some knowledge about the practical watermark process, but, the secret key is not known to him. As a result, an attacker will try to operate the data to destroy the watermark. Therefore, unauthorized parties should not be able to read or alter the watermark. Security should be assured for most watermarking applications such as the copyright protection. Sometimes, a secret key has to be used for the embedding and extraction processes. It is not possible for a user to find out whether a piece of data is watermarked until he or she has this (private) key. In other words, watermarking algorithms based on a secret key and this makes a major problem; they do not allow a public recovery of the watermark to work properly. In order to overcome this problem, public key watermarking algorithms have been

proposed. Such algorithms consist of two keys; a public key and a private key. An image, for example, can be watermarked using the private key, whereas the public key is used to verify the mark (Seitz, 2005; Karzenbeisser and Perircolas, 2000). Some public keys watermarking algorithms are discussed in Meerwald (2001); Karzenbeisser and Perircolas (2000); Qiao and Nahrstedt (1999).

1.2.5 Low Cost

One of the most important features of the watermarking algorithm is that it should have low complexity and perform simple operations (Hartung et al., 1999; Darmstaedter et al., 1998). The speed of watermarking embedding and recovery processes is important for some applications like video applications because of the large amount of data to be processed.

1.3 Watermark Attacks

The following sections highlights the four groups of attacks related to the robustness, imperceptibility, capacity, security and cost. They are geometric attacks, lossy compression attack, image processing attacks, and noise attacks.

1.3.1 Geometric Attacks

Geometric attack of watermarked images and videos refers to downscaling, cropping, rotation and frame dropping and is the major disadvantage of image and video watermarking system. These operations are not aimed at removing the watermark, but try to either destroy it or disable its detection(Li and Kwong, 2005). Furthermore, geometric attack destroys the embedding, the detection process and the synchronisation of watermarking.

1.3.2 Lossy Compression attack

Lossy compression is an algorithm that compresses a file (such as image or video), in order to reduce the size of the file, but may not maintain the integrity of the original file. This can impact negatively on any hidden data in the image or frame of video. This algorithm may "lose" unnecessary data and provides a close approximation to high-quality file, but not exactly the original. Lossy compression involves general processing which does not specifically aim to embed watermark but may accidentally destroy or damage it (Xiaoqing, 2006).

1.3.3 Image processing attack

The three filters in image processing attacks consist of low-pass filter, median filter and Wiener filter. A low-pass filter passes low-frequency signals and apart from that it also reduces the extent of signals with frequencies higher than the cut-off frequency. Furthermore, an important role is played by low-pass filters in signal processing which is identical to moving averages in some other fields, such as finance. Median filtering is a non-linear digital filtering technique which is used to remove noise from images or other signals. Furthermore, it is also an important step in image processing and is used to reduce speckle noise. It replaces a pixel with the median of all the pixels in the neighbourhood. The function of the Wiener filter is to filter out noise which has corrupted a signal by removing undesired frequencies. Image processing attack, for instance doesn't introduce considerable degradation in watermarked frames, but can dramatically affect the performance (Bovik, 2005).

1.3.4 Noise attack

Gaussian noise is a random signal with a given distribution added to the image unintentionally. In certain applications, Gaussian noise may originate from digital to analogue and analogue to digital converters, or as a consequence of transmission errors. Salt and Pepper noise is a type

of noise usually seen on images or frames of video. It represents itself as randomly occurring white and black pixels and it has been sprinkled on the image. Noise attack may introduce perceptually shaped noise with the maximum unnoticeable power. This will typically force the threshold at which the correlation detector operates to increase. Also watermark distortion is caused by Gaussian noise and Salt and Pepper noise (Bovik, 2005).

1.4 Research Motivation

It is important for digital data and multimedia, such as video, image, and music, to have digital watermarking. The importance of digital watermarking stems from the fact that digital data can be easily transformed through the Internet. In spite of the existence of watermarking technique for all kinds of digital data, most of the literature address the watermarking of still images for copyright protection and only some are extended to the temporal domain for video watermarking. There has been much emphasis on the robustness of watermarking against signal processing operations. However, it has become clear that a very small geometric distortion can prevent the detection of a watermark in many watermarking techniques. This problem is more pronounced for digital video watermark detection.

In order for a watermark to be useful, it must be perceptually invisible and robust against any possible attack and image processing by those who seek to corsair the material (Voloshynovskiy et al., 2001).

The wider applications for video watermarking have also created some additional difficulties in the two fundamental requirements of watermarking, namely robustness and imperceptibility (Koz and Alatan, 2008). There has been much emphasis on the robustness of watermarking against signal processing operations, and geometric attack is known as the most crucial issue to handle in watermarking. Moreover, a video watermarking scheme should be resistant

to a number of hostile attacks, such as image processing attack and noise attack.

1.5 Problem Statement

Digital watermarking is a general solution that can be used to identify illegal copying and ownership, authentication, or other applications by inserting information into the digital data in visible, or an invisible way Dugelay and Petitcolas (2000). The huge production of media in the Computer Mediated Systems (CMS) or over the net has created the complexity of protecting media. One of the major obstacles in image and video watermarking system is geometric attacks of watermarked images or video. Geometric attack means that a small amount of rotation or scaling could disable the receiver from detecting the watermark (Seitz, 2005).

Generally, the lack of synchronisation that is essential for watermarking detection makes geometric attacks more difficult to handle than numerical processing in watermarking. For this reason, it is still in high demand to find a watermarking method that is robust against geometric attacks. Because of these difficulties that watermarking faces, it remains one of the most difficult areas of watermarking that needs to be solved. Its difficulties also encompass still images in addition to the video. The poor performance, computational complexity and the difficulty in the implementation are the main factors in the unresolved issues in geometric attacks (Wang and Pearmain, 2006; Seitz, 2005).

Additional developments in watermarking methods are aimed at improving the security, and detection performance of these watermarks. Furthermore, the work also aims at resisting a combination of watermark attack, geometric attack, lossy compression, image processing attack and noise attack. Thus, these will be the major challenges in video watermarking.

1.6 Objectives of the Thesis

It can be observed that perceptual transparency, robustness, capacity and security are very important elements and they should be included in the performance criteria for the quality of watermarking. Imperceptibility is the degree of invisibility of the embedded watermark when the watermarked signal is displayed. Robustness is the resilience of the embedded watermark against removal of watermarking information using signal processing.

This research aims to improve existing digital video watermarking technique and design and implementation of two robust watermarking techniques based on wavelet transform and spatial domain. The main objectives of this thesis are:

- To propose digital video watermarking algorithms that support robustness and imperceptibility.
- To ensure that the proposed algorithms are more robust against the following attacks:
 1. Geometric (downscaling, rotation, cropping, and frame dropping).
 2. Lossy compression (JPEG compression)
 3. Image processing (low pass filtering, Median filtering, and Wiener filtering).
 4. Noise (Gaussian noise, Salt and Pepper noise).

1.7 Scope and Limitation

The scope of this thesis is to develop the watermarking requirements like robustness and imperceptible hiding. The majority of current data hiding researches are concerned with robust and imperceptible watermarking. As mentioned earlier, robustness refers to the resistance of the watermarked data towards any form of malicious distortion which does not render the dig-

ital data useless. The data after being embedded into video, and after compression or other processing must also be recoverable from watermarking. It must be able to resist geometric attacks, lossy data compression, filtering, and noise attacks without losing its function.

The embedding system needs to modify the data in such a way that the changes are visually imperceptible. Imperceptibility retains the perceptual quality and value of the multimedia sources. A visually meaningful grey image, such as a logo, is embedded in video, which is essentially a video editing or copyright protection. In addition, the modification is modulated by a random sequence to make it difficult to systematically remove invisible marks via an automated algorithm.

1.8 Research Approach

In order to investigate the improvement on the robustness and imperceptibility of video watermarking as well as to accomplish the research objectives, the steps involved in this research are as shown in Figure 1.4

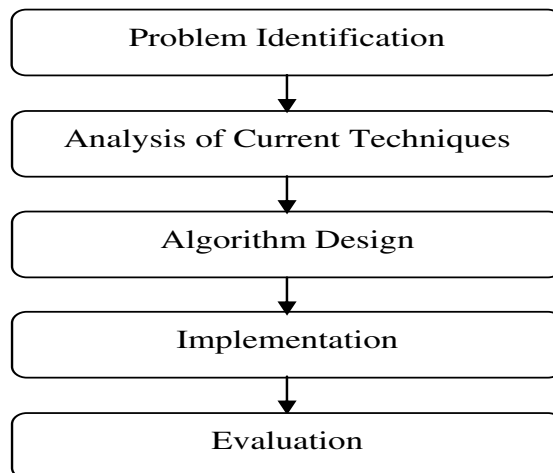


Figure 1.4: Research Approach

1.8.1 Problem Identification

Even with the challenges encountered with robust and imperceptibility digital video watermarking techniques, it remains an active topic for research. From the literature, problem identification is carried out with the aim of addressing many issues. The first issue of video watermarking is geometric attacks, which could disable the receiver from detecting the watermark. The second issue is the poor performance in the implementation of the methods in geometric attacks. The third issue is the problems of improving the security and detection performance in watermarking. Lastly, the problem of resisting a combination of watermark attacks.

1.8.2 Analysis of Current Techniques

This step focuses on current methods and algorithms, and is concerned with the robustness and invisibility. In particular, this research focuses on the robust and imperceptibility digital video watermarking. In robustness, the researchers are concerned with geometric attacks, image processing attacks, lossy compression attack, and noise attacks. Based on the literature review, there are limitations in the existing methods. Therefore, the current research will address these limitations.

1.8.3 Algorithm Design

In this step the proposed algorithms will be designed to improve the watermarking process in terms of robustness and invisibility in order to achieve the objectives of the research. Therefore, in this research, the proposed methods improve over Hartung and Girod (1998) watermarking technique by moving it to frequency domain using discrete cosine transform (DCT) and discrete wavelet transform (DWT). The current watermarking techniques have weaknesses when geometric attacks are involved. Hence, the researchers propose two new algorithms (3D-DWT and RSS) that have more resistance to geometric attacks. The study in this thesis focuses on the

design of a system against any possible attacks such as geometric attacks, lossy compression attacks, image processing attacks, and noise attacks. The watermark is embedded in I, B, and P-frame to counter the frame dropping attack because embedding the watermark in P-frame and B-frame have less capacity since they are highly compressed by motion compensation.

1.8.4 Implementation

In this step, the proposed methods will be implemented using MATLAB version 7.5 and the experiments will be performed on a Pentium 4 PC running Windows XP. The four proposed algorithms that will improve the robustness and imperceptibility will be implemented in order to achieve the objectives of the research.

1.8.5 Evaluation

This step is concerned with examining the performance efficiency of the proposed methods through evaluation of the results of the proposed methods for video watermarking algorithm with respect to two metrics: imperceptibility and robustness. The metrics were evaluated using video clips: "Susi on the phone", "Flower", "Football", "Mobile", "Tempte", and "Table Tennis" with frame count of 450, 150, 150, 450, 149, and 150 frames, with each frame having a resolution of 352×240 , 352×240 , 704×480 , 704×480 , 352×288 , and 352×240 pixels respectively.

Imperceptibility: The results of the experiment are presented in the context of peak signal to noise ratio (PSNR) to estimate the performance of the invisibility and the detection ratio of the watermarks.

Robustness: is a measurement of the invulnerability of a watermark against the attempts to remove or degrade it by different types of digital signal processing attacks. The similarity

between the original and extracted watermarks is measured using the correlation factor with a range between 0 and 1.

1.9 Thesis Contributions

1. A new spread spectrum watermarking in discrete cosine transform domain called SS-DCT. SSDCT improved an existing technique i.e. Hartung and Girod (1998).
2. A new spread spectrum watermarking in discrete wavelet transform domain called SS-DWT. SSDWT improved an existing technique i.e. Hartung and Girod (1998).
3. A new wavelet-based watermarking algorithm (3DDWT). This algorithm has high invisibility and robustness.
4. A new robust spatial watermarking algorithm (RSS). The more interesting part of this method is that it attempts to realize a good trade-off between robustness and quality of the embedding.

1.10 Thesis organisation

The organisation of the rest of the thesis is as follows: Chapter Two gives a brief introduction to digital video watermarking and its attack which is the core of this thesis.

Chapter Three presents several techniques related to video watermarking. These techniques are classified in this chapter according to the domain they operate in. A comparative analysis of different video watermarking techniques is also presented. Finally, this chapter discusses the limitations of the existing approaches that motivate this research.

Chapter Four proposed two new spread spectrums watermarking in frequency domain, namely SSDCT and SSDWT. The performance evaluation of the SSCT and SSDWT algo-

rithms have been evaluated on the basis of the imperceptibility and robustness. The experimental result is then discussed and the improved method (Hartung and Girod, 1998) is compared with the proposed methods and shows the significant effect of the SSDCT and SSDWT is then discussed.

In Chapter Five, a new multi-resolution wavelet-based watermarking technique 3DDWT is proposed. Robustness against frame dropping is proposed. Then, performance evaluation on the basis of imperceptibility and robustness, performance comparison, experimental results are reviewed.

In Chapter Six, a new robust spatial watermarking scheme called RSS is presented. The performance evaluation of the RSS algorithm has been evaluated on the basis of imperceptibility and robustness. Performance comparison, experimental results are also used to demonstrate the performance of the proposed technique.

The focus of Chapter Seven is on the overall comparison performance of all the proposed schemes. Therefore, this chapter presents experiment setup, imperceptibility, robustness, and the simulation results of performance measurement for the evaluation of the proposed methods (SSDCT, SSDWT, 3DDWT, and RSS). Experiment setup presents the performance of the proposed methods. Imperceptibility shows the quality for the watermarked frames. The robustness section explains various types of attacks and measures the proposed methods against these attacks. The quality of the watermarked video is presented and the proposed methods are compared with the existing methods.

Finally Chapter Eight concludes the thesis and suggests future work.

CHAPTER 2

BACKGROUND

2.1 Introduction

This chapter provides an overview of the fundamental concept of digital watermarking, particularly for videos. This chapter provides background knowledge and focus to the work presented in this thesis. This chapter describes watermarking terminology, basic watermark schemes, type of attacks on watermarks, pseudo-random number generators, and finally MPEG video.

2.2 Watermarking Terminology

Numerous names have been used to describe and classify watermarking techniques. In this work the following terms are used as follows:

Host is the piece of digital data in which the information is hidden, whereas payload refers to the hidden information.

Visible watermarks are visual patterns like logos, which are inserted into the digital data that can be seen by human eyes. While invisible watermarks are watermark that cannot be seen by human eyes.

Non-blind watermarking schemes are those which permit the extraction of the embedded information with the aid of the original, unwatermarked data. Its counterpart is known as blind watermarking scheme. A key to enforce security is used by some watermarking schemes. Watermarking techniques are usually referred to as secret or public watermarking techniques

due to the use of a secret or public key respectively.

Fragile watermarks are watermarks that have only very limited robustness. They are used to detect modifications of the watermarked data rather than extract non-erasable information (Marini et al., 2007; Karzenbeisser and Perircolas, 2000; Delaigle, 2000; Qiao and Nahrstedt, 1999).

2.3 Basic Watermarking Schemes

All watermarking schemes consist of three stages, namely the embedding stage (Figure 2.1), the recovery stage or extraction stage (Figure (2.2) and finally the decision stage. The embedding stage as shown in Figure (2.1), blends together the host, the payload and a public/secret key to produce the watermarked data. The secret key is used to make the watermark robust against replacement or removal of watermarked data. The recovery stage is the process of getting back the payload. The process takes watermarked data (which may be modified by a third party), the secret key and payload, and returns either the payload or a confidence measure of how probable the presence of a specific watermark is (Karzenbeisser and Perircolas, 2000; Delaigle, 2000).

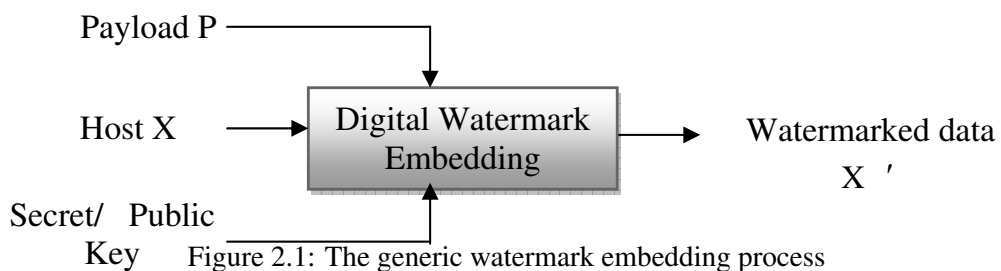


Figure 2.1: The generic watermark embedding process

In the decision stage, watermarking system analyses the extracted data (payload). Depending on the type of the application, the decision stage can produce a number of different outputs. For copyright protection, the output of the system can give from simple to more complicated answers. In the simplest case, the result is just a yes/no decision indicating if the copyright

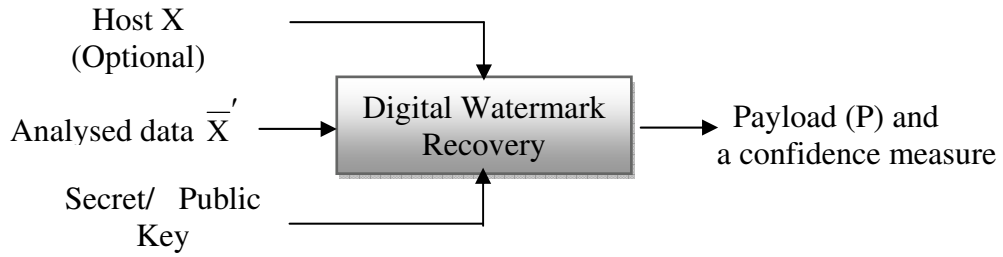


Figure 2.2: The generic watermark recovery process

holder's mark (payload) has been found in the host. The detection process uses the similarity measurement which measures the similarity between the extracted payloads against the original payload.

A widely used similarity measure that is used for the original watermark and the extracted watermark, is the normalised correlation coefficients (NCC) as shown in Gonzalez (2002).

$$NCC = \frac{\sum_X \sum_Y (W - \bar{W})(W^* - \bar{W}^*)}{[\sum_X \sum_Y (W - \bar{W})^2 \sum_X \sum_Y (W^* - \bar{W}^*)^2]^{1/2}} \quad (2.1)$$

where W and W^* refers to the original watermark and the extracted watermark respectively, and are the average value of the embedded and extracted watermark respectively, and X and Y represent the dimensions of the watermark. Another widely used measure is the normalised correlation as shown in Equation 2.2(NC) Neil et al. (2000).

$$NC = \frac{\sum_X \sum_Y W \times W^*}{\sum_X \sum_Y W.W} \quad (2.2)$$

The similarity values vary in the interval $[-1,1]$; a value well above 0 and close to 1 indicates that the extracted sequence W^* matches the embedded sequence W . Then, it can be concluded that the video has been watermarked with W .

A detection threshold T can be used to make the detection decision. If the value of NC

or NCC for example is greater than T , the watermark is considered detected. The detection threshold can be derived experimentally Cox et al. (1997) or analytically Meerwald (2001). An experimental detection threshold can be derived by calculating the correlation between many randomly generated watermarks (for example 1000) and the original embedded one as shown Figure 2.3. Analytical threshold can be defined as Equation 2.3.

$$T = \frac{a}{S * N} |f^*| \quad (2.3)$$

where S , is the standard deviation which is either 2 or 3, f^* is the data coefficients that carry the watermarked information, N is the length of data coefficients, and a is the strength of the watermark. Several authors have attempted to draw general models of watermarking. Cox

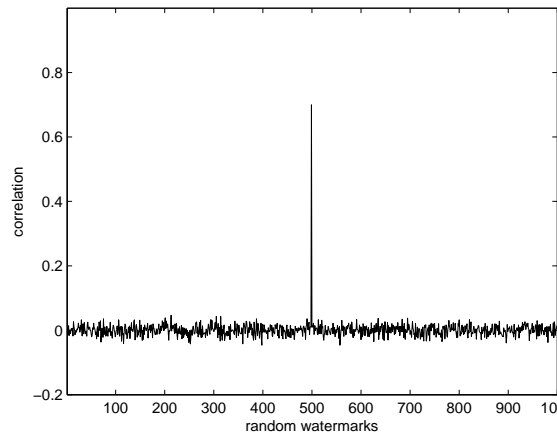


Figure 2.3: Experimental Detection

et al. (1999), proposed a general model, which describes watermarking as a communication problem. A message has to be hidden (watermarked) in a digital media such as an image. In the proposed 3DDWT method, the logo is encoded in two steps before being embedded. First, it is encrypted by using stream cipher (RC4) and thus becomes more robust. In the second step, it is modulated and takes an appropriate shape to be later added to the frame of the video. This can be a real value to be added to pixels or transformed coefficients to be added into another domain. This happens in watermark embedding.