



Contents

1	Introduction	1
2	Digital Terrestrial Television – Fundamentals and Standards	5
2.1	Stationary Television Broadcasting	5
2.1.1	History and Distribution Areas	6
2.1.2	General System Architecture	7
2.1.3	Video Characteristics	9
2.1.4	Hybrid Video Coding	10
2.1.5	Packetization and Multiplexing	13
2.1.6	Error Protection by Channel Coding	14
2.2	Mobile Television Broadcasting	16
2.2.1	History and Distribution Areas	16
2.2.2	General System Architecture and Error Protection	17
2.2.3	Video Characteristics	19
2.3	Comparative Summary	20
3	Terrestrial Broadcasting over Error-Prone Channels	23
3.1	Characteristics of Terrestrial Broadcasting	23
3.1.1	Channel Degradations	24
3.1.2	Distortion of Packetized Transport Streams	25
3.2	Detection of Transmission Errors	26
3.3	Effects on Compressed Video Signals	27
3.3.1	Dropping of Transport Stream Packets	27
3.3.2	Desynchronization during Variable Length Decoding	29
3.3.3	Error Propagation by Motion-Compensated Prediction	30
3.4	Error Resilience in Video Communications	31
3.5	State-of-the-Art Error Concealment	32
3.5.1	Objectives, Classification, and Position in Decoder	32
3.5.2	Previous Work on Spatial Concealment	34
3.5.3	Previous Work on Temporal Concealment	36



3.5.4	Previous Work on Spatio-Temporal Concealment	38
3.6	Conclusions	40
4	Inter-Sequence Error Concealment Using Low-Resolution References	41
4.1	Automotive Multi-Broadcast Reception of Stationary and Mobile TV . . .	42
4.2	Basic Concept	43
4.3	Analysis of Maximum Reconstruction Quality	45
4.4	Spatial Alignment of Synchronized Reference Signals	48
4.4.1	Problem Formulation	49
4.4.2	Pixel-Based Image Alignment	50
4.4.2.1	Minimization Problem	50
4.4.2.2	Numerical Optimization by Levenberg-Marquardt	52
4.4.2.3	Reconstruction Quality	55
4.4.3	Feature-Based Image Alignment	58
4.4.3.1	Overview	58
4.4.3.2	Scale-Invariant Feature Transform	59
4.4.3.3	Keypoint Matching	61
4.4.3.4	Model Fitting	62
4.4.3.5	Evaluation of Reconstruction Quality	64
4.5	Spatio-Temporal Alignment of Delayed Reference Signals	65
4.5.1	Algorithm	66
4.5.2	Evaluation of Reconstruction Quality and Visual Quality	68
4.5.2.1	Comparison of Alignment Approaches	69
4.5.2.2	Comparison to Classical Concealment Schemes	70
4.5.2.3	Visual Results	71
4.5.2.4	Performance for Large Loss Areas	74
4.5.2.5	Influence of Hybrid Video Coding	75
4.5.3	Complexity Evaluation	78
4.6	Conclusions	81
5	Algorithmic Enhancements for Inter-Sequence Error Concealment	83
5.1	Enhanced Feature-Based Spatial Image Alignment	83
5.1.1	Comparison of Feature Transforms	84
5.1.1.1	Overview of Feature Transforms	85
5.1.1.2	Supervised Model Fitting	85
5.1.1.3	Performance and Complexity Evaluation	88
5.1.2	Comparison of Model Fitting Techniques	91
5.1.2.1	Least-Squares Model Fitting	92
5.1.2.2	Simulation Results	93
5.2	Temporal Adaptation Strategies for Spatio-Temporal Image Alignment . .	94



5.2.1	Basic Concept	96
5.2.2	Proposed Strategies	96
5.2.3	Influence on Reconstruction Quality and Visual Quality	98
5.2.4	Complexity Evaluation	102
5.3	Enhanced Image Interpolation	103
5.3.1	Overview of Image Interpolation Techniques	104
5.3.2	Influence on Reconstruction Quality	104
5.4	Conclusions	105
6	Joint Temporal and Inter-Sequence Error Concealment	107
6.1	Motivation	107
6.2	Algorithms for Joint Error Concealment	109
6.2.1	Basic Concept	109
6.2.2	Temporal Error Concealment	110
6.2.3	Mode Selection Schemes	111
6.2.3.1	Comparison of Residuals	111
6.2.3.2	Incorporation of Local Image Statistics	112
6.2.4	Simulation Results	114
6.2.4.1	Reconstruction Quality	114
6.2.4.2	Visual Quality	117
6.2.5	Conclusions	118
6.3	Extensions	118
6.3.1	Enhanced Motion Estimation	119
6.3.1.1	Multi-Reference Image Motion Estimation	119
6.3.1.2	Block-Assisted Template Matching	121
6.3.2	Reconstruction of Displaced Frame Differences	126
6.4	Conclusions	129
7	Spatial Refinement by Frequency Selective Post Processing	131
7.1	Application to Inter-Sequence Error Concealment	131
7.1.1	Motivation and Basic Concept	131
7.1.2	Spatial Refinement by Frequency Selective Approximation	133
7.1.2.1	Overview	133
7.1.2.2	Design of Pixel Weights	134
7.1.3	Spatial Refinement by Frequency Selective Extrapolation	136
7.1.4	Simulation Results	138
7.1.4.1	Simulation Parameters	138
7.1.4.2	Evaluation of Reconstruction Quality	138
7.1.4.3	Evaluation of Visual Quality	141
7.1.4.4	Evaluation of Computational Complexity	142



7.2	Application to Joint Temporal and Inter-Sequence Error Concealment . . .	143
7.3	Conclusions	145
8	Inter-Sequence Error Concealment Using High-Resolution References	147
8.1	Automotive Multi-Broadcast Reception of Stationary TV	147
8.2	Basic Concept	148
8.3	Drift Compensation for Compressed Video	150
8.4	Simulation Results	152
8.4.1	Simulation Parameters	152
8.4.2	Evaluation of Reconstruction Quality	152
8.4.3	Evaluation of Visual Quality	155
8.5	Conclusions	156
9	Summary and Conclusions	157
A	Notation	161
A.1	Abbreviations and Acronyms	161
A.2	Mathematical Conventions, Operations, Symbols, and Units	165
B	Simulation setup	171
C	Further simulation results	173
	Bibliography	178