

Motion Picture Restoration

A.C. Kokaram

Motion Picture Restoration

**Digital Algorithms for Artefact Suppression in
Degraded Motion Picture Film and Video**



Springer

Dr Anil Kokaram
University of Cambridge
Signal Processing and Communications Laboratory
Department of Engineering
Trumpington Street
Cambridge CB2 1PZ

ISBN 978-1-4471-3487-9 ISBN 978-1-4471-3485-5 (eBook)
DOI 10.1007/978-1-4471-3485-5

British Library Cataloguing in Publication Data
Kokaram, Anil. C.

Motion picture restoration : digital algorithms for artefact suppression in degraded motion picture film and video

1. Motion pictures - Conservation and restoration 2. Image processing - Digital techniques 3. Image reconstruction

I. Title

621.3'67

ISBN 978-1-4471-3487-9

Library of Congress Cataloging-in-Publication Data
Kokaram, A. C., 1967-

Motion picture restoration : digital algorithms for artefact suppression in degraded motion picture film and video / A.C. Kokaram.

p. cm.

Includes bibliographical references.

ISBN 978-1-4471-3487-9

1. Motion picture film--Conservation and restoration. 2. Image processing--Digital techniques. 3. Signal processing--Digital techniques.

I. Title.

TR886.3.K65 1998

778.5'3'0288--dc21

98-4855

Apart from any fair dealing for the purposes of research or private study, or criticism or review, as permitted under the Copyright, Designs and Patents Act 1988, this publication may only be reproduced, stored or transmitted, in any form or by any means, with the prior permission in writing of the publishers, or in the case of reprographic reproduction in accordance with the terms of licences issued by the Copyright Licensing Agency. Enquiries concerning reproduction outside those terms should be sent to the publishers.

© Springer-Verlag London 1998

Originally published by Springer-Verlag Berlin Heidelberg New York in 1998

The use of registered names, trademarks etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant laws and regulations and therefore free for general use.

The publisher makes no representation, express or implied, with regard to the accuracy of the information contained in this book and cannot accept any legal responsibility or liability for any errors or omissions that may be made.

Typesetting: Camera ready by author
Printed and bound at The Cromwell Press, Trowbridge, Wiltshire, England
34/3830-543210 Printed on acid-free paper

To my wife, Stefanie

Preface

The manipulation of pictures and video in digital form has been an established research activity for more than twenty years. It is only recently, however, that digital image and video processing equipment has been accessible to the general public. This is due in part to the rapidly growing economy of the home computer. A major contributing factor has been the marked rise in the presence of the non-academic user on the internet, particularly the World Wide Web (WWW). Manipulating digital imagery has become synonymous with the WWW. It is the drive to present audio and visual media to the home user in an interactive form and to increase the available range of choices, which has encouraged agreements to begin digital video television broadcasting before the turn of the century. With the increased demand for video material, there is a perceived increase in demand for material from archive sources and this has fuelled commercial interest in automatic digital restoration processes. Furthermore there is a continuing effort to design techniques for correcting errors in received compressed video bit streams for the purposes of live communications links over noisy channels e.g. mobile telephones and the internet.

This book introduces the reader to a range of digital restoration activities beyond the well traversed areas of noise reduction and deblurring. It describes a number of problems associated with archived film and video. Particular attention is given to missing data since that applies equally well to correcting packet loss in coded video bit streams. The book should appeal both to those in industry and to academic researchers.

In many ways the book is a culmination of eight years work in the area of video reconstruction. This began in 1989 when I was a Ph.D student in the Signal Processing Laboratory at the Cambridge University Engineering Department and continued as a post-doctoral fellow from 1993–1998. I am grateful for

the financial support of Cambridge University, the British Library and Cable and Wireless during the early years and the European Union restoration project AURORA¹ during the last three years.

Many exceptional people influenced my thinking in this time and this book would be incomplete without suitable acknowledgement. I wish to thank Dr. Simon Godsill for many educational discussions about the Bayesian paradigm which led to the design of the JOMBADI algorithm. Much of the research performed would not have been possible were it not for the Ph.D students who gave of their time to help maintain the laboratory network: Pete Wilson, Dr. Adam Tibbalds, Ray Auchterlounie, Dr. Robert Young, Ian Calderbank, Dr. Robin Morris and Dr. M. Lai. I am grateful for many enlightening conversations with Dr. Joan Lasenby, Dr. Bill Fitzgerald, David Elias, Ben Bradshaw, Dr. Julian Magarey, Dr. Adam Tibbalds, Dr. Robin Morris, Dr. Nick Kingsbury and of course my Ph.D supervisor Dr. Peter Rayner who also arranged funding in the early years. The work of many willing proofreaders was essential in creating a coherent manuscript: Steve Armstrong, Adam Tibbalds, Ben Bradshaw, Rebecca Moore (of Springer-Verlag) and my wife, Stefanie. I am especially grateful for helpful comments from Prof. Petar M. Djurić during his short stay at Cambridge. I wish to thank every one of my colleagues in the laboratory for creating a very pleasant atmosphere for interaction.

Thanks are due to several members of the AURORA project for valuable discussions about restoration during my last few years as a post-doctoral fellow: Louis Laborelli and Jean-Hugues Chenot of I.N.A.; John Drewery, Jim Easterbrook and Theodore Vlachos at the BBC; Martin Weston and Stuart Sommerville of Snell and Wilcox and Peter van Roosmalen at Delft University. I am also grateful for the help of David Throup at Quantel (U.K.), Wolfgang Lempp and Amit Gupta at the Computer Film Company, London, for providing source material. Some of the pictures used in Chapters 5 and 8 are provided by INA, Paris, through the help of Jean-Hugues Chenot and I must also thank João Sequeira of RTP (Rádio e Televisão Portuguesa) for readily providing some of the material used in Chapters 8, 9 and 10.

Finally, I must thank my family in Trinidad for their constant support over the years. I am indebted to my wife for her encouragement, punctuation and patience while my world-view narrowed to these three hundred pages in the last few months.

I am currently in-between worlds as I take up a Lectureship in the Electrical Engineering Dept. of Trinity College, Dublin, Ireland. There I shall continue the work started in this book.

Anil Kokaram
Cambridge
January 1998

¹AUtomatic Restoration of ORiginal Archives, European Union ACTS Project AC072.

Glossary

2D	Two Dimensional
3D	Three Dimensional
AR	Autoregressive
BBC	British Broadcasting Corporation
ARMA	Autoregressive Moving Average
2DAR	Two Dimensional AR Model
3DAR	Three Dimensional AR Model
WBME	Wiener Based Motion Estimator
MWBME	Multiresolution Wiener Based Motion Estimator
AWBME	Adaptive Wiener Based Motion Estimator
BM	Block Matching
BBM	Boyce Block Matching
MRF	Markov Random Field
JOMBADI	Joint Model Based Detection and Interpolation
MCMC	Markov Chain Monte Carlo
MPEG	Motion Picture Experts Group
pdf	Probability Distribution Function
cdf	Cumulative Distribution Function
ML	Maximum Likelihood
MAP	Maximum a Posteriori
MBD	Model Based Detection
MBI	Model Based Interpolation
LS	Least Squares
SNR	Signal to Noise Ratio
MSE	Mean Square Error
MMSE	Minimum Mean Square Error
MAE	Mean Absolute Error
DFD	Displaced Frame Difference
DPD	Displaced Pixel Difference
ICM	Iterated Conditional Modes
SA	Simulated Annealing
VZO	Temporal zero-order hold interpolation for motion
Pel	Pixel
RMS	Root Mean Squared
SDI	Spike Detection Index
ROD	Rank Order Detector
ROC	Receiver Operating Characteristic
PMSE	Percentage Mean Squared Error
PIMSE	Percentage Improvement in Mean Squared Error
MMF	Multilevel Median Filter
DFT	Discrete Fourier Transform
FFT	Fast Fourier Transform
IDFT	Inverse Discrete Fourier Transform

Contents

1	Introduction	1
1.1	A short history of film and video	4
1.2	Film and video artefacts	6
1.2.1	Missing data	6
1.2.2	Noise	7
1.2.3	Image unsteadiness	7
1.2.4	Image flicker	8
1.2.5	Telecine effects	8
1.3	A rough guide to the book	9
2	Motion Estimation for Image Sequence Processing: An Over-	
	view	13
2.1	Image sequence modelling: The image centric view	15
2.1.1	Correspondence matching	16
2.1.2	Gradient based approaches	18
2.1.3	Ambiguity in motion estimation: Adaptive solutions and additional constraints	22
2.2	Block Matching vs. WBME	25
2.3	Image sequence modelling: Alternatives	26
2.3.1	A stochastic image centric sequence model	28
2.4	Estimating large displacements	32
2.5	Motion prediction	35
2.6	A unifying theory	36
2.6.1	Conceptual motion estimation	36
2.6.2	Quantitative analysis	38

2.6.3	Deriving motion estimators	40
2.7	Final comments	45
3	Three Dimensional Autoregressive Modelling for Image Sequences	47
3.1	The model	48
3.2	Parameter estimation	48
3.2.1	Estimation of the AR coefficients	49
3.2.2	Estimating the displacement	49
3.3	Experiments on artificial autoregressive sequences	51
3.3.1	Generating three dimensional autoregressive sequences	51
3.3.2	The experiments	54
3.3.3	Results and observations	54
3.3.4	Discussion	57
3.4	Experiments with a more realistic sequence	57
3.4.1	Experiments	59
3.4.2	Discussion	62
3.5	Real sequences	65
3.6	Discussion	66
3.7	Adaptive estimation	67
3.7.1	Experiments	70
3.7.2	Discussion	70
3.8	Modelling sequences with large displacements	70
3.9	Model selection on the pyramid	71
3.9.1	Experiments and discussion	73
3.10	The motion parameter in the 3DAR model: Using alternative estimators	80
3.11	Final comments	81
4	Image Sequence Restoration: A Review	85
4.1	Early techniques for noise reduction in image sequences	87
4.2	Noise reduction in image sequences	89
4.2.1	Motion compensated temporal filtering	89
4.2.2	Motion compensated spatio-temporal filtering.	91
4.3	Removing impulsive noise	92
4.3.1	Model based missing data reconstruction	95
4.4	Summary	96
5	Line Registration for Jittered Video	99
5.1	The model	100
5.2	Displacement estimation	101
5.2.1	Increasing stability	106
5.3	Implementation	106
5.3.1	Model parameter estimation and overlapped blocks	107
5.3.2	Interpolation	108
5.3.3	Multiresolution	108

5.3.4	Enhancing vertical features	108
5.4	Algorithm flow	108
5.5	Interframe processing	110
5.6	Performance	110
5.7	Real jitter	114
5.8	Final Comments	117
6	Heuristics for Reconstructing Missing Data	119
6.1	Two step removal	120
6.2	Heuristics for detecting missing data	122
6.2.1	The SDI detectors	122
6.2.2	The ROD detector	124
6.2.3	Pre-processors	125
6.2.4	Adaptive detectors	125
6.3	Motion estimation	126
6.4	Detector performance	130
6.5	Motion compensated median filtering	135
6.5.1	The filters	135
6.6	An improved spatio-temporal MMF	136
6.6.1	Motion interpolation	137
6.6.2	Interpolation performance	142
6.7	Real degradation	142
6.8	Final comments	149
7	Model Based Reconstruction for Missing Data	151
7.1	The model for degradation	152
7.2	The image data model	152
7.3	A Bayesian framework for joint detection and reconstruction	153
7.3.1	The corruption likelihood	154
7.3.2	The original (clean) data likelihood	154
7.4	The priors	155
7.4.1	The motion prior	155
7.4.2	The priors for corruption and detection	155
7.5	Solving for the unknowns	156
7.5.1	The Gibbs sampler	157
7.5.2	Adaptations to the Gibbs sampler	157
7.6	The JOMBADI algorithm	159
7.6.1	The draw for $\mathbf{d}_{n,n-1}$, $\mathbf{d}_{n,n+1}$, $\mathbf{a}$, σ_e^2	160
7.6.2	Joint sampling for $c(\mathbf{x})$, $I_n(\mathbf{x})$, $b(\mathbf{x})$	162
7.7	Relation to other techniques	162
7.7.1	Early model based systems: 1989–1996	163
7.7.2	The Morris system: 1994	170
7.7.3	The N.T.U. systems: 1994–1997	172
7.7.4	Related work in audio	175
7.7.5	The Rank Order Detector: 1996	175
7.7.6	Early work at the BBC: 1982	176

7.8	Fast algorithms	177
7.8.1	Single site interpolation	181
7.9	Performance	181
7.9.1	Interpolation	187
7.9.2	Real degradation	192
7.10	Summary comments	198
8	Large Area Reconstruction	201
8.1	An overview of the motion interpolation problem	204
8.2	Constraints on motion	208
8.2.1	Local temporal smoothness	209
8.3	The occlusion prior	210
8.4	The posterior distribution	211
8.5	Choosing the most probable motion field interpolant	213
8.5.1	Modifying the Gibbs sampler	213
8.5.2	Composition sampling	214
8.6	The algorithm	215
8.6.1	Suboptimal MAP estimation	217
8.7	Considering more severe degradation	218
8.7.1	Generating motion candidates	218
8.8	Illustrating performance	218
8.9	Real degradation	221
8.10	Final comments	224
9	Line Scratch Detection and Removal	227
9.1	Line features and model for degradation	229
9.2	Finding suspect lines	230
9.3	Bayesian refinement	233
9.3.1	Gibbs sampling	233
9.4	Line removal	235
9.5	Summary comments	238
10	Noise Reduction for Image Sequences	241
10.1	Motion compensated Wiener filtering	242
10.1.1	The 3D IIR/3D frequency domain filter	242
10.1.2	The 3D FIR filter	246
10.2	Performance	247
10.3	Real sequences	256
10.4	A note on motion estimation	259
10.5	Final comments	259
11	Using Colour	261
11.1	Heuristics for detection	261
11.2	Vector median reconstruction	262
11.3	Model based reconstruction	263
11.4	A note on colour spaces	264
11.5	Pictures	266

11.6 Final comments	267
12 Parting Remarks	269
A Estimating the AR Coefficients for the 3DAR Model	273
B The Residual from a Non-Causal AR Model is not White	277
C Estimating Displacement in the 3DAR Model	279
C.1 Summary	285
D Joint Sampling in the JOMBADI Algorithm	287
D.1 Sampling for $\mathbf{a}(\mathbf{x}), \sigma_e^2(\mathbf{x}), \mathbf{d}_{n,n-1}(\mathbf{x})$	288
D.2 Sampling for $b(\mathbf{x}), c(\mathbf{x}), I_n(\mathbf{x})$	291
E Examining Ill-Conditioning in $\mathbf{G}^T \mathbf{G}$	295
E.1 Condition for singularity	295
E.2 Relating ill-conditioning to the spatial contrast	296
E.3 Ill-conditioning in the general 3DAR solution.	298
E.4 Summary	298
F The Wiener Filter for Image Sequence Restoration	301
F.1 The 3D frequency domain/3D IIR Wiener filter	301
F.2 The 3D FIR Wiener filter	303
F.3 The matrix formulation of the 3D Wiener filter	305
G Reducing the Complexity of Wiener Filtering	307
G.1 Efficient Wiener filtering via 2D DFT diagonalization	307
G.2 An alternative derivation	310
G.3 A final refinement	313
References	315
Index	331