Decision–Feedback Equalisation with Fixed–Lag Smoothing in Nonlinear Channels

by

David Wayne Bartel

Bachelor of Applied Science (Exploration Geophysics),
Curtin University of Technology, 1982
Graduate Diploma of Applicable Mathematics,
Murdoch University, 1988
Master of Mathematical Sciences (Signal and Information Processing),
University of Adelaide, 1999

Thesis submitted for the degree of

Doctor of Philosophy

in

Electrical and Electronic Engineering
University of Adelaide

2006

Contents

Abstract

This thesis is concerned with an aspect of the field of digital signal processing, namely, the application of fixed–lag smoothing (FLS) to decision–feedback equalisation (DFE). The resultant algorithm was introduced in a recent paper and is termed herein the Fixed–Lag–Smoothing Decision–Feedback Equalisation (FLSDFE) algorithm. The motivation for studying the FLSDFE algorithm is that it may potentially improve the performance of a standard DFE algorithm, providing more reliable digital communication and data storage. This thesis extends previous results by applying the FLSDFE algorithm to linear and nonlinear channels, of minimum– or nonminimum–phase.

In chapter 2 the FLSDFE formulae are derived for two classes of nonlinear digital communication channel, both described by truncated Volterra series. Section 2.3 treats the case of MPSK and MQAM signalling, and section 2.4 treats the case of BPSK signalling. The discrete probability distribution function of the FLSDFE output estimator is given in each case.

Chapter 3 introduces state space models that capture the exact transient dynamics of the FLSDFE algorithm. The atomic model was introduced by other authors earlier, but a suboptimal aggregation of the atomic model is given that is closely linked to an existing steady–state model. Connections are shown between the state space models and the theory of integer partitions, as well as between linear recurrence relations that generalise that of the Fibonacci series.

Examples of the performance of the FLSDFE algorithm are provided in chapter 4. Two underwater–acoustic communication channels are simulated, and it is shown that the FLSDFE performs well there, giving lower bit error rates than the DFE alone. Generic channel models, both linear and cubic, minimum– and nonminimum–phase, were then simulated. These showed some peculiar characteristics of the FLSDFE algorithm's behaviour. In particular, using the steady–state models of chapter 3, we observe a pseudo–resonance with increasing SNR (that is, the existence of an optimum SNR)—this is related to the presence of previous equalisation errors.

As a caveat to the blind use of the FLSDFE over the DFE, we illustrate that it may be necessary to determine the optimum smoothing lag to use before applying the FLSDFE algorithm, especially on difficult nonlinear channels. On such channels, increasing the lag beyond this optimum may produce worse equalisation performance than at the optimum lag. Despite this word of caution, however, the FLSDFE seems to provide a robust improvement over the DFE across a broad range of channels.

Statement of Originality

This work contains no material that has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published written by another person, except where due reference has been made in the text.

I give consent to this copy of the thesis, when deposited in the University Library, being available for loan, photocopying and dissemination through the library digital thesis collection.

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Date

Acknowledgments

I would like to thank my principal academic supervisor, Lang White, for his patient and erudite supervision. Lang certainly set a high intellectual watermark that encouraged me to think rigorously. Doug Sweet, my DSTO supervisor, was meticulous in his reviews of early material, and could be relied upon to spot omissions or weaknesses in logic that I had overlooked. I appreciated Doug's penetrating questioning of my various explanations as I developed the theory. I am grateful to my colleague, Sergey Simakov, who helped me on numerous occasions with the use of LaTeX and associated desktop publishing software. Without Sergey's erudite assistance, this document would surely have been more frustrating to produce and the poorer for it.

Thanks must also surely go to my family, who provided me with the necessary backdrop of sanity and normalcy to which I could anchor. When thinking about the undertaking of a PhD I have often thought of the parody of the person who gets to be an expert on certain diseases of the back legs of a rare subspecies of Patagonian sand flea. Only a fellow expert would seem to know of or care about such things.

Lastly, but not leastly, I am grateful to DSTO for providing me with the opportunity to undertake this doctoral training. Without this support I would certainly have never undertaken such a venture in mid–career.

Publications

[1] D. W. Bartel and L. B. White, *A novel nonlinear equalizer–application to underwater acoustic communication*, Proceedings of ACOUSTICS 2002 Conference, Adelaide, South Australia, 13–15 November 2002.

[2] D. W. Bartel and L. B. White, *Decision–feedback equalization with fixed–lag smoothing in nonlinear channels*, Proceedings of Defense Applications of Signal Processing Conference, Midway, Utah, March 27–April 1, 2005.

[3] D. W. Bartel, *Generalised differential encoding for underwater acoustic communication*, Proceedings of ACOUSTICS 2005 Conference, Busselton, Western Australia, 9–11 November 2005.

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Glossary

BER	Bit–Error Rate, 110, 114–116
BPSK	Binary Phase–Shift Keying, vii, 2, 3, 6, 9, 10, 12, 13, 23, 24, 26, 27, 29–36, 41, 45, 52, 56, 65, 66, 68, 77, 78, 85, 86, 88, 90–93, 96, 97, 108, 110, 115, 124, 131, 132, 134
DFE	Decision–Feedback Equalisation, vii, 1, 2, 4, 9, 17, 26, 27, 29, 31, 32, 36, 41, 42, 44, 56, 66, 69, 76, 85, 101, 116, 126, 130–133
DSTO	Australia's Defence Science and Technology Organisation, xi, 2
EM	Expectation–Maximization, 14
FIR	Finite–Impulse Response, 4–6, 9, 14, 17, 26, 27, 29–31, 41, 52, 56, 76, 85, 86, 90, 92, 106, 108, 110, 115, 131
FLS	Fixed–Lag Smoothing, vii
FLSDFE	Fixed–Lag–Smoothing Decision–Feedback Equalisation, vii, 2–7, 9, 10, 12, 14, 15, 17, 18, 23, 24, 26–32, 43, 45, 75, 76, 78, 82, 84, 90, 101, 102, 106, 108, 110, 114, 116, 123, 125, 126, 130, 131, 133, 134, 137, 139, 140
FSMP	Finite–State Markov Process, 29, 31, 85–88, 90–93, 132
ISI	Intersymbol Interference, 1
LSB	Least–Significant Bit, 34, 82

MPSK	*M*–ary Phase–Shift Keying, vii, 2, 5, 9, 12, 13, 20, 22, 23, 27, 131, 134
MQAM	*M*–ary Quadrature–Amplitude Modulation, vii, 5, 9, 12, 13, 20, 22, 27, 131, 134
MSB	Most–Significant Bit, 34, 37, 79
PSK	Phase–Shift Keying, 2
QAM	Quadrature–Amplitude Modulation, 2
QPSK	Quadrature Phase–Shift Keying, also known as *Quaternary* Phase–Shift Keying, 12, 13, 21, 22, 30, 41, 90
RGS	Restricted–Growth String, 86, 87
SISO	Single–Input Single–Output, 9, 12, 15, 23, 28, 108, 114, 131, 134
SNR	Signal–to–Noise Ratio, vii, 7, 12, 110, 112, 115, 116, 123, 125, 129