Towards Unsupervised Online Band Selection in Hyperspectral Imaging

by

Gautam Balasubramanian

B.E. (Computer-Systems),
University of Technology, Sydney, Australia, 2003.
MSc. (Elec. Eng),
Monash University, Melbourne, Australia, 2005.

Thesis submitted for the degree of

Doctor of Philosophy

in

School of Electrical and Electronic Engineering
The University of Adelaide, Australia

December 2013

Typeset in $\LaTeX\,2_\varepsilon$
Gautam Balasubramanian

To my Beautiful Wife, Loving Parents and Omnisicent Teachers

Contents

Abstract

This thesis explores the problem of unsupervised selection of a set of spectral wavebands in a hyperspectral sensor for a surveillance task. Selecting a subset of wavebands for surveillance has the advantage of reducing data throughput and hence network bandwidth requirements, computational complexity for processing the data and storage requirements in a ground-station. For the sensor designer, Signal-To-Noise Ratio and other sensor-band improvements can be made on those bands deemed critical for the surveillance task. In chapters 3 and 4, we propose the use of locally correlated high-dimensional Gaussian Mixture models to account for band overlap where maximum likelihood estimates of the parameters of such a model are provided using the SAGE-EM (Space Alternating Generalised Expectation Maximisation) algorithm. In both these chapters convex-relaxation strategies are proposed to handle the combinatorial complexity of selecting a subset-of bands that are locally correlated and contain non-Gaussian measurements. However, in chapter 4, we select bands according to anomaly detection criteria as opposed to modelling estimation accuracy (likelihood) as done in chapter 3. We breakdown the problem such that any pixel contains band measurements that belong to either an outlier or partial background distribution, where the distributions diverge across band-subsets in a Kullback-Leibler (KL) divergence sense. A pixel is deemed as an anomaly if it contains a certain number of outliers. We identify the bands that contain the most number of contiguous outlier measurements and also subsequently reveal the presence of anomalies. Finally, in the last chapter we solve the problem of online band selection for sub-pixel compositional hyperspectral models using a Bayesian approach. Online band-selection enables spectral-band cueing and automation for adaptive focal plane arrays where not all bands are used to measure each pixel. We apply beta process models to provide a recursive strategy to select bands based on prior knowledge of their utility as well as bands used in neighbouring pixels. Band utility is measured through convex-relaxation as the subset of bands that provides the best abundance estimation accuracy of training data. The combination of a Gaussian process prior for possible end-members (pure materials) as well as a Gamma distributions for the abundance, enables efficient posterior sampling from a joint Normal-Gamma distribution. Furthermore, natural spectral band variations are retained making the model suitable for band selection, where approximate sum-to-one constraints are enforced through an intelligent update of the Gamma hyperparameters, based on the Dirichelet-Gamma relation. Experiments are conducted on synthetic Gaussian Mixture data with additive noise (Chapters 3, 4), Rochester Institute of Technology (RIT) Target Detection Test using the HyMAP sensor, (Chapter 4), synthetic sub-pixel data created using USGS spectral database [1] (Chapter 4) and AVIRIS-Cuprite dataset used by Mittelman et.al. in [2] (Chapter 4).

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 or 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.

The author of this thesis acknowledges that copyright of published work contained within this thesis (as listed in the publications page) resides with the copyright holder(s) of that work.

Signed

Date

Acknowledgments

It is said that success has many fathers and failures but one. I measure success by personal growth rather than gain and in this sense I consider the journey thus far, a success. There are many contributors that have enabled this growth, one not greater or lesser in importance than the other both personally and academically.

Personally, my gorgeous wife, Prabha had to put up with me rushing to submit a conference paper on the first night of our marriage, alas it was the first of many more nights where her husband was missing, lost in equations within the confines of the study. Her enthusiasm for my work, belief in my abilities and passion for her husband's success made me work harder, gave me the constancy of effort required, she was always an un-ending source of encouragement and inspiration. She also instilled a sense of discipline I previously did not possess, an attribute of hers which I always hope to emulate. Thank You for the Umpteen Sacrifices, Love You heaps gorgeous. Next, my parents, who always gave me the freedom to pursue my own dreams throughout my Masters and now my PhD, selflessly, even though they knew it would keep me away from home, it must have been very difficult. Their presence always gave me perspective and reminded me to appreciate all facets of life and to never forgo responsibilities to wife, family and society although I am sure I did plenty of times. I'll always be eternally grateful for their presence in my life. I hope I have made you proud Mum n Dad. Finally, my mother-in-law and grandma who gave me constant nourishment, never shy from cooking up a storm with or without my behest also showing interest and enthusiasm on the outcomes of my work, where would I be without your kindness. I'll be eternally grateful for the sacrifice and faith of all my family members, this PhD is as much theirs as it is mine.

Academically, my principal Supervisor Professor Lang White, he's truly my first academic teacher from whom I have learned the most. His level of intelligence, comfort, enthusiasm and care with subjects of Maths and Signal Processing was a sight to behold, a memory to treasure and I hope to emulate that throughout my career. Through many informal chats, emails and presentation of his own work he also gave me a great deal of structure to my thinking and improved my ability to frame problems which opened up creative avenues to solve problems and translated to a higher standard of work. Finally, his general niceness, fairness as a human being and compassion to myself and fellow students always made him a pleasure to be around. Secondly, Dr Jason Williams who is a Senior Research Scientist at DSTO: Jason was a force to behold. I tried picking-up many tid-bits, from the way he expressed himself mathematically on the whiteboard and paper, the way he attacked problems, his vast knowledge-base about a variety of different fields and unending thirst to gain knowledge. Jason also introduced the Machine Learning and Bayesian aspects to my work bringing to my attention the latest and greatest techniques relevant to problems pursued. His humility and work habits is something I always hope to emulate. My secondary Supervisors Dr Vittala Shettigara and Dr Tim Payne, bestowed the faith in me to pursue a PhD in-spite of our research group being short-staffed, remained steadfast with their commitment for which I'll always be grateful. Vittal, introduced me to the Band Selection problem and brought to my attention the significance of almost all the sub-problems pursued in this thesis always imparting the notion of presentation and completeness. Tim's timely feedback during the initial stages of my PhD also made me think deeper about framing Maximum Likelihood Estimation as a Convex Optimisation problem. Dr Sanjeev Arulampalam a Senior Research Scientist at DSTO and Professor Ian Fuss gave me the self-belief and faith to pursue the PhD and beyond, with vigour and to receive their encouraging words from people of stature made a striking difference to my work. Gratitude must also be extended to my peers at Adelaide Uni mainly Jiang He and Yassir. You made the journey very pleasant with your cheerful demeanour and inquisitiveness in my work. To the staff in the HSI group at DSTO, thank you for your patience and sacrifice in taking on a greater workload due to my constant absence.

Finally, to my Teachers at Chinmaya Mission, you set me off on this journey in 2003 and this work is but my humble offering to You. I hope it is worthy.

Gautam Balasuramanian (August 2013)

List of Figures

List of Tables