SpringerBriefs in Electrical and Computer Engineering

Signal Processing

More information about this series at http://www.springer.com/series/11560

Samuel Davey · Neil Gordon
Ian Holland · Mark Rutten · Jason Williams

Bayesian Methods in the Search for MH370

Springer Open

Samuel Davey
National Security and ISR Division
Defence Science and Technology Group
Edinburgh, SA
Australia

Neil Gordon
National Security and ISR Division
Defence Science and Technology Group
Edinburgh, SA
Australia

Ian Holland
Cyber and Electronic Warfare Division
Defence Science and Technology Group
Edinburgh, SA
Australia

Mark Rutten
National Security and ISR Division
Defence Science and Technology Group
Edinburgh, SA
Australia

Jason Williams
National Security and ISR Division
Defence Science and Technology Group
Edinburgh, SA
Australia

ISSN 2191-8112 ISSN 2191-8120 (electronic)
SpringerBriefs in Electrical and Computer Engineering
ISSN 2196-4076 ISSN 2196-4084 (electronic)
SpringerBriefs in Signal Processing
ISBN 978-981-10-0378-3 ISBN 978-981-10-0379-0 (eBook)
DOI 10.1007/978-981-10-0379-0

Library of Congress Control Number: 2015960765

Printed on acid-free paper

This Springer imprint is published by SpringerNature
The registered company is Springer Science+Business Media Singapore Pte Ltd.

Foreword I

Uncertainty is all pervasive—whether it relates to everyday personal choices and actions, or as background to business and policy decisions, or economic and climate predictions. In recent times, few things have attracted as much attention as the uncertainty surrounding the final whereabouts of MH370.

How to deal scientifically with uncertainty? Put simply, on the one hand there are events or outcomes of interest that we don't know; on the other hand, pieces of information that we judge relevant in some sense that we do know. We need to assess what we believe about the unknowns, given the knowns.

Formalising our measure of uncertainty in terms of probabilities, the scientific approach is encapsulated in the so-called Bayesian statistical paradigm, in which beliefs about the unknowns are quantified by a probability measure conditional on what we know.

But typically, our state of knowledge itself gets modified over time and a method is therefore needed to refine and update beliefs as new information is acquired and assembled. The logical, mathematical rule for carrying out this updating is Bayes theorem, hence the term Bayesian Methods to describe the analytic and computational toolkit that has been developed for updating beliefs as evidence changes or is added to.

It is this toolkit that has been employed in the search for MH370 and this fascinating book provides a blow-by-blow case account of how the various strands of evidence have been brought together to give an overall probabilistic assessment of the final whereabouts of the plane.

This has been an extremely complex task and the authors are to be congratulated on setting out systematically and coherently the science and mathematics driving the evidential equations. But, in addition to the complex modelling there remains the task of pulling out the Bayesian probability messages from the tangle of data that has been assembled. The computational methods for achieving this are of relatively recent origin and, on a personal note, I am delighted to have played a small part, with Dr. Neil Gordon, in the signal processing revolution that is now the particle filter method of analysis.

Dr. Gordon and his colleagues have employed these methods to provide a marvellous case study demonstrating the power of mathematical modelling and computation to attack one of the most intractable uncertain puzzles of recent times.

London, UK
November 2015

Professor Sir Adrian Smith
FRS, Vice Chancellor
University of London

Foreword II

The disappearance of the Malaysian Airlines flight MH370 from air traffic control radar on the evening of 8 March 2014 with 227 passengers and 12 crew on board was a tragedy and remains a mystery until we are able to locate the flight recorder or the wreckage. Only then can we unravel what actually occurred.

Initially, the multinational search and recovery effort was focused on the Gulf of Thailand and the South China Sea. However, following closer analysis of Inmarsat data and flight path projections the search shifted to the Indian Ocean.

The Malaysian government accepted the Australian government's offer to take the lead in the search and recovery operation in the southern Indian Ocean. Australia, led by the Australian Transport Safety Bureau (ATSB), took responsibility for defining the underwater search area in 28 April 2014.

The Defence Science and Technology (DST) Group, being the only Australian government agency with the combined knowledge and experience in the scientific disciplines to support the search for MH370, became involved from May 2014. Defence scientists contributed a range of expertise across a spectrum of technologies to the search: underwater acoustics, satellite communication systems and statistical data processing.

DST Group's position as a trusted government adviser with stewardship of the full range of defence technologies has been critical to our ability to contribute to the multi-agency—and multinational-search. Our ability to provide high quality, internationally respected, rapid response is built on our deep foundational research capability. Our support to the MH370 incident is an example of scientific research feeding directly into an active operational search.

The quest for the MH370 demonstrates our ability to 'work the full problem' with a team of internationally-recognised experts contributing to the ATSB working group. Indeed, DST Group is proud to have been able to contribute its world-renowned expertise to the ATSB-led search. However, this book is not about the search for MH370. Rather, it focuses on the work to define the search zone.

We are particularly fortunate to have Dr. Neil Gordon leading the DST Group team. Dr. Gordon is recognised internationally as an expert in statistical data processing and, in particular, the dynamic Bayesian estimation methods deployed in this activity.

Working alongside Dr. Gordon are other Defence scientists—Dr. Samuel Davey, Dr. Mark Rutten and Dr. Jason Williams who are all experts in target tracking and multi-sensor fusion, and Dr. Ian Holland who specialises in satellite and wireless communications.

DST Group's expertise and unique capabilities will continue to contribute to the ongoing search for the MH370, led by the ATSB and in collaboration with other Australian and international agencies.

Canberra, Australia
November 2015

Dr. Alex Zelinsky
Chief Defence Scientist
Defence Science and Technology
Department of Defence

Acknowledgements

This book is a summary of our work as members of the MH370 Flight Path Reconstruction group. The group comprised members from Inmarsat, Thales, Boeing, US National Transportation Safety Board (NTSB) and the UK Air Accidents Investigation Branch (AAIB). The group has been expertly led by the Australian Transport Safety Bureau (ATSB).

To all our friends and colleagues at the ATSB: During many intense and stressful times you always remained calm and assured. You are dedicated professionals.

To the Flight Path reconstruction working group: We thank you all for freely sharing your expert knowledge and for working together both independently and collaboratively in such a positive way. We also thank you for sharing your forthright opinions and views and questioning everything.

To our friends and colleagues at the Defence Science and Technology Group: We would particularly like to thank Gerald Bolding and Balachander Ramamurthy for their support to the satellite data analysis and David Liebing for all his efforts in drawing the team together.

The material in Chap. 11 related to the Reunion Island debris find was developed with David Griffin from CSIRO Marine and Atmospheric Research in Hobart. Thank you David for hosting us and sharing your knowledge.

We thank Sanjeev Arulampalam (DST Group, Australia), Vaughan Clarkson (University of Queensland, Australia), Simon Godsill (Cambridge University, UK), Fredrik Gustafsson (Linköping University, Sweden), Simon Maskell (Liverpool University, UK), and Thomas Schön (Uppsala University, Sweden) for their thoughtful and helpful comments and suggestions. We thank Brian Anderson for communicating some minor corrections to the presentation.

All those involved in the search for MH370 remain totally committed to finding the aircraft and helping find closure for the families involved.

Contents

About the Authors

Samuel Davey received the Bachelor of Engineering, Master of Mathematical Science and Ph.D. degrees from the University of Adelaide, Australia, in 1996, 1999 and 2003, respectively. Since 1995 he has worked for the Defence Science and Technology Group, Australia, in the areas of target tracking, tracker performance assessment and multi-sensor fusion. He is a Visiting Research Fellow at the University of Adelaide and a Senior Member of the IEEE.

Neil Gordon received a Ph.D. in Statistics from Imperial College London in 1993. He was with the Defence Evaluation and Research Agency in the UK until 2002 working on missile guidance and statistical data processing. He is best known for initiating the particle filter approach to nonlinear, non-Gaussian dynamic estimation, which is now in widespread use throughout the world in many diverse disciplines. He is the co-author/co-editor of two books on particle filtering. In 2002 he moved to the Defence Science and Technology Group in Adelaide, Australia, where he is currently head of Data and Information Fusion. In 2014 he became an Honorary Professor with the School of Information Technology and Electrical Engineering at the University of Queensland. He is a Senior Member of the IEEE.

Ian Holland received the Bachelor of Electronic and Communication Engineering in 2000 and a Ph.D. in wireless telecommunications in 2005, both from Curtin University of Technology, Western Australia. Since then he has held positions in the University of Western Australia, the Institute for Telecommunications Research at the University of South Australia, EMS Satcom Pacific and Lockheed Martin Australia. Since January 2011, Ian has been working as a Research Scientist in Protected Satellite Communications at the Defence Science and Technology Group.

Mark Rutten received the Bachelor of Science, Bachelor of Engineering and Master of Mathematical Science from the University of Adelaide in 1995, 1996 and 1999, respectively, and a Ph.D. from the University of Melbourne in 2005 on Multipath Tracking for Over the Horizon Radars. He has worked on data and information fusion for the Defence Science and Technology Group since 1996. His research interests include nonlinear state estimation, target tracking and multi-sensor fusion.

Jason Williams received degrees of Bachelor of Engineering in Electronics and Bachelor of Information Technology from Queensland University of Technology in 1999, Master of Science in Electrical Engineering from the United States Air Force Institute of Technology in 2003, and Ph.D. in Electrical Engineering and Computer Science from Massachusetts Institute of Technology in 2007. He worked for several years as an engineering officer in the Royal Australian Air Force, before joining Australia's Defence Science and Technology Group in 2007. He is also an Adjunct Senior Lecturer at the University of Adelaide. His research interests include target tracking, sensor resource management, Markov random fields and convex optimisation.

Acronyms

9M-MRO	Registration number of the accident aircraft
AAIB	Air Accidents Investigation Branch (United Kingdom)
ACARS	Aircraft Communications Addressing and Reporting System
ACCESS-G	Australian Community Climate and Earth-System Simulator Global model
AES	Aircraft Earth Station (the aircraft satellite communications unit)
ATC	Air Traffic Control
ATSB	Australian Transport Safety Bureau
BFO	Burst Frequency Offset
BTO	Burst Time Offset
cdf	Cumulative Distribution Function
CI	Cost Index (used to automatically control air speed)
CMH	Constant Magnetic Heading navigation
CMT	Constant Magnetic Track navigation
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CTH	Constant True Heading navigation
CTT	Constant True Track navigation
DST Group	Defence Science and Technology Group, Australia
GES	Ground Earth Station (the ground component of the satellite communications system)
HPD	Highest Posterior Density
JACC	Joint Agency Coordination Centre
KL	Kuala Lumpur
LNAV	Lateral NAVigation
NEES	Normalised Estimation Error Squared
NTSB	National Transportation Safety Board (United States)
OU	Ornstein–Uhlenbeck process

pdf	Probability Density Function
RMS	Root Mean Squared
SATCOM	Satellite communications
SIR	Sample Importance Resample particle filter
UTC	Coordinated Universal Time