

An Introduction to Multisensor Data Fusion

DAVID L. HALL, SENIOR MEMBER, IEEE, AND JAMES LINAS

Invited Paper

Multisensor data fusion is an emerging technology applied to Department of Defense (DoD) areas such as automated target recognition, battlefield surveillance, and guidance and control of autonomous vehicles, and to non-DoD applications such as monitoring of complex machinery, medical diagnosis, and sensor buildings. Techniques for multisensor data fusion are drawn from a wider range of areas including artificial intelligence, pattern recognition, statistical estimation, and other areas. This paper provides a tutorial on data fusion, introducing data fusion applications, process models, and identification of applicable techniques. Comments are made on the state-of-the-art in data fusion.

I. INTRODUCTION

In recent years, multisensor data fusion has received significant attention for both military and nonmilitary applications. Data fusion techniques combine data from multiple sensors, and related information from associated databases, to achieve improved accuracies and more specific inferences than could be achieved by the use of a single sensor alone [1]–[4]. The concept of multisensor data fusion is hardly new. Humans and animals have evolved the capability to use multiple senses to improve their ability to survive. For example, it may not be possible to assess the quality of an edible substance based solely on the sense of vision or touch, but evaluation of edibility may be achieved using a combination of sight, touch, smell, and taste. Similarly, while one is unable to see around corners or through vegetation, the sense of hearing can provide advanced warning of impending dangers. Thus multisensory data fusion is naturally performed by animals and humans to achieve more accurate assessment of the surrounding environment and identification of threats, thereby improving their chances of survival.

While the concept of data fusion is not new, the emergence of new sensors, advanced processing techniques, and improved processing hardware make real-time fusion of data increasingly possible [5], [6]. Just as the advent of symbolic processing computers (viz., the SYMBOLIC™

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computer and the Lambda machine) in the early 1970's provided an impetus to artificial intelligence [119], recent advances in computing and sensing have provided the ability to emulate, in hardware and software, the natural data fusion capabilities of humans and animals. Currently, data fusion systems are used extensively for target tracking, automated identification of targets, and limited automated reasoning applications. Spurred by significant expenditures by the Department of Defense (DoD), data fusion technology has rapidly advanced from a loose collection of related techniques, to an emerging true engineering discipline with standardized nomenclature (see Fig. 1), collections of robust mathematical techniques [2]–[4], and established system design principles. Software in the area of data fusion applications is becoming available in the commercial marketplace [16].

Applications for multisensor data fusion are widespread. Military applications include: automated target recognition (e.g., for smart weapons), guidance for autonomous vehicles, remote sensing, battlefield surveillance, and automated threat recognition systems, such as identification-friend-or-foe (IFFN) systems [14]. Nonmilitary applications include monitoring of manufacturing processes, condition-based maintenance of complex machinery, robotics [129], and medical applications. Techniques to combine or fuse data are drawn from a diverse set of more traditional disciplines including: digital signal processing, statistical estimation, control theory, artificial intelligence, and classic numerical methods [16], [12], [5]–[4]. Historically, data fusion methods were developed primarily for military applications. However, in recent years these methods have been applied to civilian applications, and there has been bidirectional technology transfer [5]. Various annual conferences provide a forum for discussing data fusion applications and techniques [7]–[10].

In principle, fusion of multisensor data provides significant advantages over single source data. In addition to the statistical advantage gained by combining same-source data (e.g., obtaining an improved estimate of a physical phenomena via redundant observations), the use of multiple types of sensors may increase the accuracy with which a quantity can be observed and characterized. In the accompanying

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Qin Zhang

Multi Sensor Data Fusion An Introduction:

Multi-Sensor Data Fusion H.B. Mitchell, 2007-07-13 The purpose of this book is to provide an introduction to the theories and techniques of multi sensor data fusion. The book has been designed as a text for a one semester graduate course in multi sensor data fusion. It should also be useful to advanced undergraduates in electrical engineering or computer science who are studying data fusion for the first time and to practising engineers who wish to apply the concepts of data fusion to practical applications. The book is intended to be largely self contained in so far as the subject of multi sensor data fusion is concerned although some prior exposure to the subject may be helpful to the reader. A clear understanding of multi sensor data fusion can only be achieved with the use of a certain minimum level of mathematics.

It is therefore assumed that the reader has a reasonable working knowledge of the basic tools of linear algebra, calculus and simple probability theory. More specific results and techniques which are required are explained in the body of the book or in appendices which are appended to the end of the book. Data Fusion: Concepts and Ideas H B Mitchell, 2012-02-09 This textbook provides a comprehensive introduction to the concepts and idea of multisensor data fusion. It is an extensively revised second edition of the author's successful book *Multi Sensor Data Fusion An Introduction* which was originally published by Springer Verlag in 2007. The main changes in the new book are New Material. Apart from one new chapter there are approximately 30 new sections, 50 new examples and 100 new references. At the same time material which is out of date has been eliminated and the remaining text has been rewritten for added clarity. Altogether the new book is nearly 70 pages longer than the original book. Matlab code. Where appropriate we have given details of Matlab code which may be downloaded from the worldwide web. In a few places where such code is not readily available we have included Matlab code in the body of the text. Layout. The layout and typography has been revised. Examples and Matlab code now appear on a gray background for easy identification and advanced material is marked with an asterisk. The book is intended to be self contained. No previous knowledge of multi sensor data fusion is assumed although some familiarity with the basic tools of linear algebra, calculus and simple probability is recommended. Although conceptually simple the study of multi sensor data fusion presents challenges that are unique within the education of the electrical engineer or computer scientist. To become competent in the field the student must become familiar with tools taken from a wide range of diverse subjects including neural networks, signal processing, statistical estimation, tracking algorithms, computer vision and control theory. All too often the student views multi sensor data fusion as a miscellaneous assortment of different processes which bear no relationship to each other. In contrast in this book the processes are unified by using a common statistical framework. As a consequence the underlying pattern of relationships that exists between the different methodologies is made evident. The book is illustrated with many real life examples taken from a diverse range of applications and contains an extensive list of modern references.

Multisensor Data Fusion David Hall, James Llinas, 2001-06-20 The emerging technology of multisensor data fusion has a

wide range of applications both in Department of Defense DoD areas and in the civilian arena. The techniques of multisensor data fusion draw from an equally broad range of disciplines including artificial intelligence, pattern recognition and statistical estimation. With the rapid evolution of computers and the maturation of data fusion technology the door to using data fusion in everyday applications is now wide open and presenting great opportunities. **The Handbook of Multisensor Data Fusion** provides a unique comprehensive and up to date resource for data fusion systems designers and researchers. Divided into five parts it offers a thorough introduction to data fusion terminology and models, describes advanced techniques for data association, target tracking and identification, presents practical information on system development including requirements analysis, systems engineering, algorithm selection, database design, human computer interfaces and performance assessment, introduces applications from the DoD, NASA, DARPA and condition based monitoring of complex machinery, supplies data fusion resources and Web sites. The contributing authors are all recognized leaders in data fusion and have collaborated to provide what promises to be the definitive reference for this rapidly developing field. Whether you are a researcher, system designer, implementer or student in the **Handbook of Multisensor Data Fusion** you'll find everything you need from a basic introduction and survey of data fusion technology to advanced mathematics and theory including very practical advice on data fusion system development and implementation. **Mathematical Techniques in Multisensor Data Fusion** David Lee Hall, 1992. This invaluable reference offers the most comprehensive introduction available to the concepts of multisensor data fusion. It introduces key algorithms, provides advice on their utilization and raises issues associated with their implementation. With a diverse set of mathematical and heuristic techniques for combining data from multiple sources the book shows how to implement a data fusion system, describes the process for algorithm selection, functional architectures and requirements for ancillary software and illustrates man machine interface requirements and database issues. **Mathematical Techniques in Multisensor Data Fusion** David Lee Hall, Sonya A. H. McMullen, 2004. Since the publication of the first edition of this book advances in algorithms, logic and software tools have transformed the field of data fusion. The latest edition covers these areas as well as smart agents, human computer interaction, cognitive aides to analysis and data system fusion control. Data fusion system this book guides you through the process of determining the trade offs among competing data fusion algorithms, selecting commercial off the shelf COTS tools and understanding when data fusion improves systems processing. Completely new chapters in this second edition explain data fusion system control, DARPA's recently developed TRIP model and the latest applications of data fusion in data warehousing and medical equipment as well as defence systems.

Multi-Sensor Data Fusion with MATLAB Jitendra R. Raol, 2009-12-16. Using MATLAB examples wherever possible **Multi-Sensor Data Fusion with MATLAB** explores the three levels of multi sensor data fusion: MSDF, kinematic level fusion including the theory of DF, fuzzy logic and decision fusion and pixel and feature level image fusion. The authors elucidate DF strategies, algorithms and performance evaluation mainly. **Handbook of Multisensor Data Fusion** Martin Liggins II, David

Hall,James Llinas,2017-01-06 In the years since the bestselling first edition fusion research and applications have adapted to service oriented architectures and pushed the boundaries of situational modeling in human behavior expanding into fields such as chemical and biological sensing crisis management and intelligent buildings *Handbook of Multisensor Data Fusion Theory and Practice Second Edition* represents the most current concepts and theory as information fusion expands into the realm of network centric architectures It reflects new developments in distributed and detection fusion situation and impact awareness in complex applications and human cognitive concepts With contributions from the world's leading fusion experts this second edition expands to 31 chapters covering the fundamental theory and cutting edge developments that are driving this field New to the Second Edition Applications in electromagnetic systems and chemical and biological sensors Army command and combat identification techniques Techniques for automated reasoning Advances in Kalman filtering Fusion in a network centric environment Service oriented architecture concepts Intelligent agents for improved decision making Commercial off the shelf COTS software tools From basic information to state of the art theories this second edition continues to be a unique comprehensive and up to date resource for data fusion systems designers

Multisensor Fusion Estimation Theory and Application Liping Yan,Lu Jiang,Yuanqing Xia,2020-11-11 This book focuses on the basic theory and methods of multisensor data fusion state estimation and its application It consists of four parts with 12 chapters In Part I the basic framework and methods of multisensor optimal estimation and the basic concepts of Kalman filtering are briefly and systematically introduced In Part II the data fusion state estimation algorithms under networked environment are introduced Part III consists of three chapters in which the fusion estimation algorithms under event triggered mechanisms are introduced Part IV consists of two chapters in which fusion estimation for systems with non Gaussian but heavy tailed noises are introduced The book is primarily intended for researchers and engineers in the field of data fusion and state estimation It also benefits for both graduate and undergraduate students who are interested in target tracking navigation networked control etc

Novel Algorithms and Techniques in Telecommunications, Automation and Industrial Electronics

Tarek Sobh,Khaled Elleithy,Ausif Mahmood,Mohammad A. Karim,2008-08-15 *Novel Algorithms and Techniques in Telecommunications Automation and Industrial Electronics* includes a set of rigorously reviewed world class manuscripts addressing and detailing state of the art research projects in the areas of Industrial Electronics Technology and Automation Telecommunications and Networking *Novel Algorithms and Techniques in Telecommunications Automation and Industrial Electronics* includes selected papers from the conference proceedings of the International Conference on Industrial Electronics Technology and Automation IETA 2007 and International Conference on Telecommunications and Networking TeNe 07 which were part of the International Joint Conferences on Computer Information and Systems Sciences and Engineering CISSE 2007 *The Electrical Engineering Handbook - Six Volume Set* Richard C. Dorf,2018-12-14 In two editions spanning more than a decade The Electrical Engineering Handbook stands as the definitive reference to the

multidisciplinary field of electrical engineering Our knowledge continues to grow and so does the Handbook For the third edition it has grown into a set of six books carefully focused on specialized areas or fields of study Each one represents a concise yet definitive collection of key concepts models and equations in its respective domain thoughtfully gathered for convenient access Combined they constitute the most comprehensive authoritative resource available Circuits Signals and Speech and Image Processing presents all of the basic information related to electric circuits and components analysis of circuits the use of the Laplace transform as well as signal speech and image processing using filters and algorithms It also examines emerging areas such as text to speech synthesis real time processing and embedded signal processing Electronics Power Electronics Optoelectronics Microwaves Electromagnetics and Radar delves into the fields of electronics integrated circuits power electronics optoelectronics electromagnetics light waves and radar supplying all of the basic information required for a deep understanding of each area It also devotes a section to electrical effects and devices and explores the emerging fields of microlithography and power electronics Sensors Nanoscience Biomedical Engineering and Instruments provides thorough coverage of sensors materials and nanoscience instruments and measurements and biomedical systems and devices including all of the basic information required to thoroughly understand each area It explores the emerging fields of sensors nanotechnologies and biological effects Broadcasting and Optical Communication Technology explores communications information theory and devices covering all of the basic information needed for a thorough understanding of these areas It also examines the emerging areas of adaptive estimation and optical communication Computers Software Engineering and Digital Devices examines digital and logical devices displays testing software and computers presenting the fundamental concepts needed to ensure a thorough understanding of each field It treats the emerging fields of programmable logic hardware description languages and parallel computing in detail Systems Controls Embedded Systems Energy and Machines explores in detail the fields of energy devices machines and systems as well as control systems It provides all of the fundamental concepts needed for thorough in depth understanding of each area and devotes special attention to the emerging area of embedded systems Encompassing the work of the world's foremost experts in their respective specialties The Electrical Engineering Handbook Third Edition remains the most convenient reliable source of information available This edition features the latest developments the broadest scope of coverage and new material on nanotechnologies fuel cells embedded systems and biometrics The engineering community has relied on the Handbook for more than twelve years and it will continue to be a platform to launch the next wave of advancements The Handbook's latest incarnation features a protective slipcase which helps you stay organized without overwhelming your bookshelf It is an attractive addition to any collection and will help keep each volume of the Handbook as fresh as your latest research

Image Processing for Remote Sensing C.H. Chen, 2007-10-17 Edited by leaders in the field with contributions by a panel of experts Image Processing for Remote Sensing explores new and unconventional mathematics methods The coverage

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Multisensor, Multisource Information Fusion-architectures, Algorithms, and Applications ... ,2004 *Multisensor Fusion* Anthony K. Hyder,E. Shahbazian,E. Waltz,2002-07-31 Proceedings of the NATO Advanced Study Institute on Multisensor Data Fusion held in Pitlochry Perthshire Scotland June 25 July 7 2000 *Sensor and Data Fusion* Lawrence A. Klein,2004 This book illustrates the benefits of sensor fusion by considering the characteristics of infrared microwave and

millimeter wave sensors including the influence of the atmosphere on their performance Applications that benefit from this technology include vehicular traffic management remote sensing target classification and tracking weather forecasting military and homeland defense Covering data fusion algorithms in detail Klein includes a summary of the information required to implement each of the algorithms discussed and outlines system application scenarios that may limit sensor size but that require high resolution data *Multisensor Fusion and Integration for Intelligent Systems* Lee Suk-han, Hanseok Ko, Hernssoo Hahn, 2009-05-28 The field of multi sensor fusion and integration is growing into significance as our society is transitioning into ubiquitous computing environments with robotics services everywhere under ambient intelligence What surrounds us are to be the networks of sensors and actuators that monitor our environment health security and safety as well as the service robots intelligent vehicles and autonomous systems of ever heightened autonomy and dependability with integrated heterogeneous sensors and actuators The field of multi sensor fusion and integration plays key role for making the above transition possible by providing fundamental theories and tools for implementation This volume is an edition of the papers selected from the 7th IEEE International Conference on Multi Sensor Integration and Fusion IEEE MFI 08 held in Seoul Korea August 20-22 2008 Only 32 papers out of the 122 papers accepted for IEEE MFI 08 were chosen and requested for revision and extension to be included in this volume The 32 contributions to this volume are organized into three parts Part I is dedicated to the Theories in Data and Information Fusion Part II to the Multi Sensor Fusion and Integration in Robotics and Vision and Part III to the Applications to Sensor Networks and Ubiquitous Computing Environments To help readers understand better a part summary is included in each part as an introduction The summaries of Parts I II and III are prepared respectively by Prof Hanseok Ko Prof Sukhan Lee and Prof Hernssoo Hahn

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Agricultural Technologies Qin Zhang, 2023-10-11 Digital agriculture is an emerging concept of modern farming that refers to managing farms using modern Engineering Information and Communication Technologies EICT aiming at increasing the overall efficiency of agricultural production improving the quantity and quality of products and optimizing the human labor required and natural resource consumption in operations This encyclopedia is designed to collect the summaries of knowledge on as many as subjects or aspects relevant to ECIT for digital agriculture present such knowledge in entries and arrange them alphabetically by articles titles Springer Major Reference Works platform offers Live Update capability Our reference work takes full advantage of this feature which allows for continuous improvement or revision of published content electronically The Editorial Board Dr Irwin R Donis Gonzalez University of California Davis Dept Biological and Agricultural Engineering Davis USA Section Postharvest Technologies Prof Paul Heinemann Pennsylvania State University Department Head of Agricultural and Biological Engineering PA USA Section Technologies for Crop Production Prof Manoj Karkee Washington State University Center for Precision and Automated Agricultural Systems Washington USA Section Robotics and Automation Technologies Prof Minzan Li China Agricultural University Beijing China Section Precision Agricultural

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