

Phase unwrapping algorithms for radar interferometry: residue-cut, least-squares, and synthesis algorithms

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The advent of interferometric synthetic aperture radar for geophysical studies has resulted in the need for accurate, efficient methods of two-dimensional phase unwrapping. Inference of the lost integral number of cycles in phase measurements is critical for three-pass surface deformation studies as well as topographic mapping and can result in an order of magnitude increase in sensitivity for two-pass deformation analysis. While phase unwrapping algorithms have proliferated over the past ten years, two main approaches are currently in use. Each is most useful only for certain restricted applications. All these algorithms begin with the measured gradient of the phase field, which is subsequently integrated to recover the unwrapped phases. The earliest approaches in interferometric applications incorporated residue identification and cuts to limit the possible integration paths, while a second class using least-squares techniques was developed in the early 1990's. We compare the approaches and find that the residue-cut algorithms are quite accurate but do not produce estimates in regions of moderate phase noise. The least-squares methods yield complete coverage but at the cost of distortion in the recovered phase field. A new synthesis approach, combining the cuts from the first class with a least-squares solution, offers greater spatial coverage with less distortion in many instances. © 1998 Optical Society of America (S0740-3230/98/030586-03\$05.00)

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1. INTRODUCTION

Algorithms that relate individual phase measurements on a two-dimensional field, motivated largely by interest in interferometric synthetic aperture radar (SAR) techniques, have proliferated over the past ten years.¹⁻⁴ These algorithms seek to infer the integral number of cycles lost when a phase measurement is made from a two-dimensional complex signal amplitude observation, which uniquely identifies only the phase value modulo 2π . We refer to such algorithms here as phase unwrapping, as distinguished from the use of that term for reconstruction of signal amplitudes from frequency-domain phase data, a common problem associated with one-dimensional signal processing.

We report here a comparison of several of the phase unwrapping algorithms in more common use today and identify and contrast the strengths and weaknesses of each. We also present a synthesis approach that combines some of the more effective features of the existing algorithms and can extend the range of phase unwrapping situations amenable to automated solution. Rather than revolutionize present capabilities, these new algorithms represent another approach for phase unwrapping procedures that aid in some situations where the existing algorithms fare poorly. Because we (1) do not review each existing algorithm comprehensively, (2) do propose new variations of the algorithms suited to particular styles of input data, and (3) do not believe that the existing set of approaches is the final word on phase unwrapping procedures, this article serves more as a progress re-

port rather than as a review of phase unwrapping procedures.

The advent of interferometric SAR for geophysical studies, in particular, has resulted in the need for accurate, efficient methods of two-dimensional phase unwrapping. Radar methods for fast and precise measurement of topographic data,^{5,6} determination of centimeter-level surface deformation fields,⁷⁻⁹ and surface velocity fields^{10,11} all require that the relative phases over large areas be known. Strictly speaking, each of these techniques requires, in addition, knowledge of the absolute phase values;¹² however, in practice contextual clues or known fiducial values (tie points) often permit geophysical inference with only the relative phases, given that the phase field is unwrapped.

Although many insights into underlying surface processes may be obtained by visual inspection of the initial, wrapped radar interferogram,^{13,14} this unwrapping by eye may be applied only to simple phase fields without significant and complicated structure. Moreover, automated topographic mapping approaches and the application of three-pass deformation algorithms are precluded by the necessity of human interaction on a pixel-by-pixel level with the interferometric data. For instance, even a small-area topographic map may contain millions of meter-spaced points. Accuracy also drives the requirement. In regions of finely spaced fringes, it may be difficult to estimate the phase manually to better than a large fraction of a cycle accuracy, whereas performance of the radar system itself allows accuracies corresponding to

Phase Unwrapping Algorithms For Radar Interferometry

Dennis C. Ghiglia, Mark D. Pritt



Phase Unwrapping Algorithms For Radar Interferometry:

Remote Sensing Image Processing Algorithms for Detecting Air Turbulence Patterns Maged

Marghany, 2024-11-22 Injuries due to air turbulence has increased recently therefore there is considerable concern and interest in understanding and detecting it more accurately Presently hardly any research deals with air turbulence detection using remote sensing images Most works use conventional optical remote sensing data with classical methods such as a library spectral signature band ratio and principal component analysis without designating new methods and technology Very little research has attempted to implement optical and microwave remote sensing images for air turbulence detections This book provides new image processing procedures for air turbulence detection using advanced remote sensing images and quantum image processing Currently there is a huge gap between research work in the field of air turbulence detection and advanced remote sensing technology Most of the theories are not operated in terms of software modules Most of the software packages in the field of remote sensing images cannot deal with advanced image processing techniques in air turbulence detections due to heavy mathematics work In this view this book fills a gap between advanced remote sensing technology and air turbulence detection For instance quantum image processing with a new generation of remote sensing technology such as RADARSAT 2 SAR images is also implemented to provide accurate air turbulence detections

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Ground Based Synthetic Aperture Radar Motoyuki Sato, Wei-ke Feng, Yuta Izumi, Amila Karunathilake, 2024-12-30 Ground based synthetic aperture radar GB SAR is used to effectively mitigate natural disasters and monitor social infrastructure such as bridges dams and airport pavement surfaces This book explains the fundamentals of radar technology the principles of synthetic aperture radar SAR image generation and interferometric SAR InSAR processing for observing small ground surface deformation less than 1 mm More advanced multiple input multiple output MIMO radar for ground surface observation is introduced The authors also provide examples of GB SAR used for monitoring landslide and vegetation to show its potential and limitations Understanding this advanced technology and its applications will help readers plan and install GB SAR systems in real life projects Features Introduces GB SAR an advanced tool that measures in millimeter ground surface displacement Explains how the GB SAR system can be installed for landslide monitoring Provides a new radar technology that monitors vibrations of infrastructure remotely Discusses the advanced radar technology related to polarimetry and interferometry Includes several case studies applying the tools and techniques discussed to natural disasters such as landslides volcanoes glaciers and so on This book is intended for civil professionals who deal with disaster mitigation and infrastructure monitoring and those in electrical engineering including radar technology It is also an excellent resource for upper level undergraduate and graduate students taking courses in remote sensing and photogrammetry geography geodesy information science engineering and geology as well as researchers and scientists interested in learning the techniques and technologies for collecting analyzing managing and visualizing geospatial data sets

Surface Displacement Measurement from Remote Sensing Images Olivier

Cavalié, Emmanuel Trouve, 2022-05-25 Drastic improvements in both access to satellite images and data processing tools today allow near real time observation of Earth surface deformations Remote sensing imagery is thus a powerful reliable and spatially dense source of information that can be used to understand the Earth and its surface manifestations as well as mitigate natural hazards This book offers for the first time a complete overview of the methodological approaches developed to measure surface displacement using synthetic aperture radar SAR and optical imagery as well as their applications in the monitoring of major geophysical phenomena More specifically the first part of the book presents the theory behind SAR interferometry InSAR and image correlation and its latest developments In the second part most of the geophysical phenomena that trigger Earth surface deformations are reviewed Surface Displacement Measurement from Remote Sensing Images unveils the potential and sensitivity of the measurement of Earth surface displacements from remote sensing imagery

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economy It helps us to create a more reliable flexible and robust society But software often falls short of our expectations Current methodologies tools and techniques remain expensive and are not yet sufficiently reliable while many promising approaches have proved to be no more than case by case oriented methods This book contains extensively reviewed papers from the thirteenth International Conference on New Trends in software Methodology Tools and Techniques SoMeT_14 held in Langkawi Malaysia in September 2014 The conference provides an opportunity for scholars from the international research community to discuss and share research experiences of new software methodologies and techniques and the contributions presented here address issues ranging from research practices and techniques and methodologies to proposing and reporting solutions for global world business The emphasis has been on human centric software methodologies end user development techniques and emotional reasoning for an optimally harmonized performance between the design tool and the user Topics covered include the handling of cognitive issues in software development to adapt it to the user s mental state and intelligent software design in software utilizing new aspects on conceptual ontology and semantics reflected on knowledge base system models This book provides an opportunity for the software science community to show where we are today and where the future may take us *The Eruption of Soufrière Hills Volcano, Montserrat, from 1995 to 1999* Timothy H. Druitt, B. Peter Kokelaar, 2002 *Energy Minimization Methods in Computer Vision and Pattern Recognition* Mario Figueiredo, Josiane Zerubia, 2001-08-22 This book constitutes the refereed proceedings of the Third International Workshop on Energy Minimization Methods in Computer Vision and Pattern Recognition EMMCVPR 2001 held in Sophia Antipolis France in September 2001 The 42 revised full papers presented were carefully reviewed and selected from 70 submissions The book offers topical sections on probabilistic models and estimation image modeling and synthesis clustering grouping and segmentation optimization and graphs and shapes curves surfaces and templates **Applications of Photonic Technology 2** George A. Lampropoulos, Roger A. Lessard, 2013-11-11 This book presents a current review of photonic technologies and their applications The papers published in this book are extended versions of the papers presented at the International Conference on Applications of Photonic Technology ICAPT 96 held in Montreal Canada on July 29 to August 1 1996 The theme of this event was Closing the Gap Between Theory Developments and Applications The term photonics covers both optics and optical engineering areas of growing scientific and commercial importance throughout the world It is estimated that photonic technology related applications to increase exponentially over the next few years and will play a significant role in the global economy by reaching a quarter of a trillion of US dollars by the year 2000 The global interest and advancements of this technology are represented in this book where leading scientists of twenty two countries with advanced technology in photonics present their latest results The papers selected herein are grouped to address six distinct areas of photonic technology The reader will find throughout the book a combination of invited and contributed papers which reflect the state of the art today and provide some insight about the future of this technology The first two papers are invited

They discuss business aspects of photonic engineering. One examines if chip to chip interconnections by means of optical technology are a good economic choice while the other discusses the photonic technology from an entrepreneurial viewpoint. Papers related to materials and considered for photonic applications e.g. **Optical Metrology and Optoacoustics in Nondestructive Evaluation of Materials** Zinovy Nazarchuk, Leonid Muravsky, Dozyslav Kuryliak, 2023-05-23. This book includes the description, modeling and realization of new optical metrology techniques for technical diagnostics of materials. Special attention is paid to multi-step phase shifting interferometry with arbitrary phase shifts between interferograms, phase shifting and correlation digital speckle pattern interferometry, optical digital speckle correlation and digital image correlation as well as dynamic speckle patterns analysis. Optoacoustic techniques can be treated as a separate branch of optical metrology and can solve many problems of technical diagnostics including detection and localization of subsurface defects in laminated composite materials. The utility of such techniques can be increased by illumination of the object via acoustic waves at certain frequencies. Hence an effective theoretical approach to the modeling of an elastic wave field interaction with an interphase defect and to defect visualization using dynamic speckle patterns is also included in this book. The experimental proof of the proposed approaches was achieved using a specially created hybrid optical digital system for detection of different subsurface defects. This book is intended for engineers, researchers and students engaged in the field of nondestructive evaluation of materials and technical diagnostics of structural elements, hybrid optical systems, speckle metrology and optoacoustic imaging techniques. *Journal of the Optical Society of America*, 2002. **Non-Destructive Evaluation (NDE) of Polymer Matrix Composites** Vistas M. Karbhari, 2013-06-30. The increased use of polymer matrix composites in structural applications has led to the growing need for a very high level of quality control and testing of products to ensure and monitor performance over time. Non-destructive evaluation (NDE) of polymer matrix composites explores a range of NDE techniques and the use of these techniques in a variety of application areas. Part one provides an overview of a range of NDE and NDT techniques including eddy current testing, shearography, ultrasonics, acoustic emission and dielectrics. Part two highlights the use of NDE techniques for adhesively bonded applications. Part three focuses on NDE techniques for aerospace applications including the evaluation of aerospace composites for impact damage and flaw characterisation. Finally, the use of traditional and emerging NDE techniques in civil and marine applications is explored in part four. With its distinguished editor and international team of expert contributors, Non-destructive evaluation (NDE) of polymer matrix composites is a technical resource for researchers and engineers using polymer matrix composites, professionals requiring an understanding of non-destructive evaluation techniques and academics interested in this field. Explores a range of NDE and NDT techniques and considers future trends. Examines in detail NDE techniques for adhesively bonded applications. Discusses NDE techniques in aerospace applications including detecting impact damage, ultrasonic techniques and structural health monitoring. Springer Handbook of Experimental Solid Mechanics William N. Sharpe,

Jr., William N. Sharpe, 2008-12-04 The Springer Handbook of Experimental Solid Mechanics documents both the traditional techniques as well as the new methods for experimental studies of materials components and structures The emergence of new materials and new disciplines together with the escalating use of on and off line computers for rapid data processing and the combined use of experimental and numerical techniques have greatly expanded the capabilities of experimental mechanics New exciting topics are included on biological materials MEMS and NEMS nanoindentation digital photomechanics photoacoustic characterization and atomic force microscopy in experimental solid mechanics Presenting complete instructions to various areas of experimental solid mechanics guidance to detailed expositions in important references and a description of state of the art applications in important technical areas this thoroughly revised and updated edition is an excellent reference to a widespread academic industrial and professional engineering audience Learning Approaches in Signal Processing Wan-Chi Siu, Lap-Pui Chau, Liang Wang, Tieniu Tang, 2018-12-07 Coupled with machine learning the use of signal processing techniques for big data analysis Internet of things smart cities security and bio informatics applications has witnessed explosive growth This has been made possible via fast algorithms on data speech image and video processing with advanced GPU technology This book presents an up to date tutorial and overview on learning technologies such as random forests sparsity and low rank matrix estimation and cutting edge visual signal processing techniques including face recognition Kalman filtering and multirate DSP It discusses the applications that make use of deep learning convolutional neural networks random forests etc The applications include super resolution imaging fringe projection profilometry human activities detection capture gesture recognition spoken language processing cooperative networks bioinformatics DNA and healthcare Analysis of Images, Social Networks and Texts Mikhail Yu. Khachay, Natalia Konstantinova, Alexander Panchenko, Dmitry Ignatov, Valeri G. Labunets, 2015-12-04 This book constitutes the proceedings of the Fourth International Conference on Analysis of Images Social Networks and Texts AIST 2015 held in Yekaterinburg Russia in April 2015 The 24 full and 8 short papers were carefully reviewed and selected from 140 submissions The papers are organized in topical sections on analysis of images and videos pattern recognition and machine learning social network analysis text mining and natural language processing *Advances in SAR: Sensors, Methodologies, and Applications* Timo Balz, Uwe Soergel, Mattia Crespi, Batuhan Osmanoglu, 2018-10-22 This book is a printed edition of the Special Issue Advances in SAR Sensors Methodologies and Applications that was published in Remote Sensing

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