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-square solution, offers greater spatial coverage with less distortion in many instances. © 1998 Optical Society of America [S0740-3232(98)01403-3]

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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 report 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 posts. 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

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Léo Pomar

Phase Unwrapping Algorithms For Radar Interferometry:

Two-Dimensional Phase Unwrapping Dennis C. Ghiglia,Mark D. Pritt,1998-04-28 A resource like no other the first comprehensive guide to phase unwrapping Phase unwrapping is a mathematical problem solving technique increasingly used in synthetic aperture radar SAR interferometry optical interferometry adaptive optics and medical imaging In Two Dimensional Phase Unwrapping two internationally recognized experts sort through the multitude of ideas and algorithms cluttering current research explain clearly how to solve phase unwrapping problems and provide practicable algorithms that can be applied to problems encountered in diverse disciplines Complete with case studies and examples as well as hundreds of images and figures illustrating the concepts this book features A thorough introduction to the theory of phase unwrapping Eight algorithms that constitute the state of the art in phase unwrapping Detailed description and analysis of each algorithm and its performance in a number of phase unwrapping problems C language software that provides a complete implementation of each algorithm Comparative analysis of the algorithms and techniques for evaluating results A discussion of future trends in phase unwrapping research Foreword by former NASA scientist Dr John C Curlander Two Dimensional Phase Unwrapping skillfully integrates concepts algorithms software and examples into a powerful benchmark against which new ideas and algorithms for phase unwrapping can be tested This unique introduction to a dynamic rapidly evolving field is essential for professionals and graduate students in SAR interferometry optical interferometry adaptive optics and magnetic resonance imaging MRI *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 Artificial Intelligence in Digital Holographic Imaging Inkyu Moon,2022-12-20 Artificial Intelligence in Digital Holographic Imaging Technical Basis and Biomedical Applications An eye opening discussion of 3D optical sensing imaging analysis and pattern recognition

Artificial intelligence AI has made great progress in recent years Digital holographic imaging has recently emerged as a powerful new technique well suited to explore cell structure and dynamics with a nanometric axial sensitivity and the ability to identify new cellular biomarkers By combining digital holography with AI technology including recent deep learning approaches this system can achieve a record high accuracy in non invasive label free cellular phenotypic screening It opens up a new path to data driven diagnosis Artificial Intelligence in Digital Holographic Imaging introduces key concepts and algorithms of AI to show how to build intelligent holographic imaging systems drawing on techniques from artificial neural networks convolutional neural networks and generative adversarial network Readers will be able to gain an understanding of the basics for implementing AI in holographic imaging system designs and connecting practical biomedical questions that arise from the use of digital holography with various AI algorithms in intelligence models What s Inside Introductory background on digital holography Key concepts of digital holographic imaging Deep learning techniques for holographic imaging AI techniques in holographic image analysis Holographic image classification models Automated phenotypic analysis of live cells For readers with various backgrounds this book provides a detailed discussion of the use of intelligent holographic imaging system in biomedical fields with great potential for biomedical application **Journal of the Optical Society of America** ,2002 **Three-Dimensional Television** H.M. Ozaktas,Levent Onural,2007-11-13 Advances in optical technology and computing power are bringing life like 3DTV closer with potential applications not only in entertainment but also in education scientific research industry medicine and many other areas 3DTV will require the integration of a diversity of key technologies from computing to graphics imaging to display and signal processing to communications The scope of this book reflects this diversity different chapters deal with different stages of an end to end 3DTV system such as capture representation coding transmission and display Both autostereoscopic techniques which eliminate the need for special glasses and allow viewer movement and holographic approaches which have the potential to provide the truest three dimensional images are covered Some chapters discuss current research trends in 3DTV technology while others address underlying topics This book is essential to those with an interest in 3DTV related research or applications and also of interest to those who while not directly working on 3DTV work in areas which developments in 3DTV may touch such as multimedia computer games virtual reality medical imaging and scientific simulation **Robust Phase Unwrapping and Its Applications in Radar Signal Processing and Imaging** Xiaowei Li,2011 Phase unwrapping is the reconstruction of a phase function on a grid given the value modulo 2pi of the function on the grid This is an important process in signal and image processing An important technique in phase unwrapping is to use the Chinese remainder theorem CRT to determine a true frequency from its multiple wrapped versions remainders It is well known that the CRT has tremendous applications in many fields but it is not robust in the sense that a small error in any remainders may cause a large error in the reconstruction result which is well known not robust This is perhaps why CRT has applications in cryptography but not

desired in some other applications such as frequency estimation from undersampled waveforms with its applications for example phase unwrapping in radar signal processing and sensor networks Recently a robust phase unwrapping algorithm has been proposed that has already found applications in multi baseline multifrequency multi speed multi stepped frequency multi pulse repetition frequency SAR imaging for moving targets Regarding the computational complexity of this robust phase unwrapping algorithm an efficient implementation is developed to reduce the two dimensional searching of its original into a one dimensional searching and therefore reduces the complexity significantly What is more motivated from the robust phase unwrapping algorithm a general form of robust CRT is proposed i e robust reconstruction of general large integers from their remainders with errors This case often occurs in practical applications that is the reason why a robust solution is urgently needed In terms of reconstruction of large integers from remainders it is not restricted to co prime moduli and this unique reconstruction is possible if and only if the large integers are less than the least common multiple lcm of all the moduli Note that this proposed algorithm is for a general real number for those with zero fractional errors the algorithm then leads to a fast robust CRT Further some applications based on this robust algorithm are developed including a robust Doppler ambiguity resolution using multiple paired pulse repetition frequencies PRF This new algorithm is based on this robust phase unwrapping algorithm and the Ferrari B erenguer Alengrin FBA method using multiple pulse repetition frequencies PRF Our simulation results show that the newly proposed algorithm significantly outperforms the FBA method and is also better than the robust phase unwrapping algorithm Moreover another important topic and application location and imaging of elevated moving targets using multiple frequency velocity synthetic aperture radar SAR is well investigated and proposed In this dissertation we propose an antenna array approach with cross track interferometry in which multiple wavelength signals are transmitted It is shown that our proposed multiple frequency interferometric velocity SAR MFIn VSAR by applying our proposed robust phase unwrapping algorithm can locate both slowly and fast moving elevated targets correctly An integrated MFIn VSAR algorithm for moving target imaging is also presented **Scientific Satellite and Moon-Based Earth Observation for Global Change** Huadong Guo,Wenxue Fu,Guang Liu,2019-06-27 Global change involves complex and far reaching variations in the Earth s systems and satellite observations have been widely used in global change studies Over the past five decades Earth observation has developed into a comprehensive system that can conduct dynamic monitoring of the land the oceans and the atmosphere at the local regional and even global scale At the same time although a large number of Earth observation satellites have been launched very few of them are used in global change studies The lack of scientific satellite programs greatly hinders research on global change This book proposes using a series of global change scientific satellites to establish a scientific observation grid for global environmental change monitoring from space and offers the first comprehensive review of lunar based Earth observation These scientific satellites could provide not only basic datasets but also scientific support in facilitating advances in international global change

research **Earthquakes** Taher Zouaghi,2017-02-01 This book is devoted to diverse aspects of earthquake researches especially to new achievements in seismicity that involves geosciences assessment and mitigation Chapters contain advanced materials of detailed engineering investigations which can help more clearly appreciate predict and manage different earthquake processes Different research themes for diverse areas in the world are developed here highlighting new methods of studies that lead to new results and models which could be helpful for the earthquake risk The presented and developed themes mainly concern wave s characterization and decomposition recent seismic activity assessment mitigation and engineering techniques The book provides the state of the art on recent progress in earthquake engineering and management The obtained results show a scientific progress that has an international scope and consequently should open perspectives to other still unresolved interesting aspects **Image Processing, Signal Processing, and Synthetic Aperture Radar for Remote Sensing** Jacky Desachy,Shahram Tajbakhsh,Consiglio nazionale delle ricerche (Italy),1997 **InSAR Crustal Deformation Monitoring, Modeling and Error Analysis** Yu Chen,Junshi Xia,Chen Yu,Bingqian Chen,2022-10-11 *International Conference on Experimental Mechanics* ,2002 *New Trends in Software Methodologies, Tools and Techniques* A. Selamat,H. Fujita,H. Haron,2014-08-29 Software is the essential enabling means for science and the new 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 **IEEE International Geoscience and Remote Sensing Symposium Proceedings** ,2003 **Vision Sensors and Edge Detection** Jose H. Espina-Hernandez,2010-08-12 Vision Sensors and Edge Detection book reflects a selection of recent developments within the area of vision sensors and edge detection There are two sections in this book The first section presents vision sensors with applications to panoramic vision sensors wireless vision sensors and automated vision sensor inspection and the second one shows image processing

techniques such as image measurements image transformations filtering and parallel computing   **New Simple DSPI Setups and Improvement of Noise Tolerance of DSPI** Xu Ding,2004   **IGARSS 2004** ,2004   International Symposium on Multispectral Image Processing (ISMIP'98) Ji Zhou,1998 This volume comprises papers on multispectral image processing They discuss issues such as processing of hyperspectral remote sensing images 3d object understanding from 2D images occlusion detectable stereo for 3D image media and fast route planning approach to aircraft

International Symposium on Multispectral Image Processing (ISMIP'...) ,1998   **Journal of Atmospheric and Oceanic Technology** ,2002   Journal of the Royal Society, Interface ,2006

The Top Books of the Year Phase Unwrapping Algorithms For Radar Interferometry The year 2023 has witnessed a noteworthy surge in literary brilliance, with numerous engrossing novels captivating the hearts of readers worldwide. Lets delve into the realm of top-selling books, exploring the fascinating narratives that have enthralled audiences this year. The Must-Read : Colleen Hoovers "It Ends with Us" This heartfelt tale of love, loss, and resilience has captivated readers with its raw and emotional exploration of domestic abuse. Hoover skillfully weaves a story of hope and healing, reminding us that even in the darkest of times, the human spirit can succeed. Uncover the Best : Taylor Jenkins Reids "The Seven Husbands of Evelyn Hugo" This spellbinding historical fiction novel unravels the life of Evelyn Hugo, a Hollywood icon who defies expectations and societal norms to pursue her dreams. Reids captivating storytelling and compelling characters transport readers to a bygone era, immersing them in a world of glamour, ambition, and self-discovery. Discover the Magic : Delia Owens "Where the Crawdads Sing" This captivating coming-of-age story follows Kya Clark, a young woman who grows up alone in the marshes of North Carolina. Owens crafts a tale of resilience, survival, and the transformative power of nature, captivating readers with its evocative prose and mesmerizing setting. These popular novels represent just a fraction of the literary treasures that have emerged in 2023. Whether you seek tales of romance, adventure, or personal growth, the world of literature offers an abundance of compelling stories waiting to be discovered. The novel begins with Richard Papen, a bright but troubled young man, arriving at Hampden College. Richard is immediately drawn to the group of students who call themselves the Classics Club. The club is led by Henry Winter, a brilliant and charismatic young man. Henry is obsessed with Greek mythology and philosophy, and he quickly draws Richard into his world. The other members of the Classics Club are equally as fascinating. Bunny Corcoran is a wealthy and spoiled young man who is always looking for a good time. Charles Tavis is a quiet and reserved young man who is deeply in love with Henry. Camilla Macaulay is a beautiful and intelligent young woman who is drawn to the power and danger of the Classics Club. The students are all deeply in love with Morrow, and they are willing to do anything to please him. Morrow is a complex and mysterious figure, and he seems to be manipulating the students for his own purposes. As the students become more involved with Morrow, they begin to commit increasingly dangerous acts. The Secret History is a brilliant and thrilling novel that will keep you guessing until the very end. The novel is a cautionary tale about the dangers of obsession and the power of evil.

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