

Article

Morphological Signal Processing for Phenotype Recognition of Human Pluripotent Stem Cells Using Machine Learning Methods

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Abstract: Human pluripotent stem cells have the potential for unlimited proliferation and controlled differentiation into various somatic cells, making them a unique tool for regenerative and personalized medicine. Determining the best clone selection is a challenging problem in this field and requires new sensing instruments and methods able to automatically assess the state of a growing colony ('phenotype') and make decisions about its destiny. One possible solution for such label-free, non-invasive assessment is to make phase-contrast images and/or videos of growing stem cell colonies, process the morphological parameters ('morphological portrait', or signal), link this information to the colony phenotype, and initiate an automated protocol for the colony selection. As a step in implementing this strategy, we used machine learning methods to find an effective model for classifying the human pluripotent stem cell colonies of three lines according to their morphological phenotype ('good' or 'bad'), using morphological parameters from the previously published data as predictors. We found that the model using cellular morphological parameters as predictors and artificial neural networks as the classification method produced the best average accuracy of phenotype prediction (67%). When morphological parameters of colonies were used as predictors, logistic regression was the most effective classification method (75% average accuracy). Combining the morphological parameters of cells and colonies resulted in the most effective model, with a 99% average accuracy of phenotype prediction. Random forest was the most efficient classification method for the combined data. We applied feature selection methods and showed that different morphological parameters were important for phenotype recognition via either cellular or colonial parameters. Our results indicate a necessity for retaining both cellular and colonial morphological information for predicting the phenotype and provide an optimal choice for the machine learning method. The classification models reported in this study could be used as a basis for developing and/or improving automated solutions to control the quality of human pluripotent stem cells for medical purposes.

Keywords: human pluripotent stem cells; human embryonic stem cells; machine learning; best clone; morphological phenotype



Citation: Vedeneeva, E.; Gursky, V.; Samsonova, M.; Neganova, I. Morphological Signal Processing for Phenotype Recognition of Human Pluripotent Stem Cells Using Machine Learning Methods. *Biomedicines* **2023**, *11*, 3005. <https://doi.org/10.3390/biomedicines11113005>

Academic Editor: Aline Yen Ling Yang

Received: 12 October 2023

Revised: 30 October 2023

Accepted: 6 November 2023

Published: 9 November 2023



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1. Introduction

Assessment of the cellular morphology of biological samples has a long history, as it provides essential information on many underlying cellular processes and cellular states. In cell cultures, morphology is usually employed as a measure of cell classification; in clinical practice, morphological criteria are applied for diagnosis, prognosis, and treatment of human diseases. In recent years, quantification of cell morphology has seen great advances

Morphological Methods In Image And Signal Processing

Vijay Madisetti



Morphological Methods In Image And Signal Processing:

Morphological Methods in Image and Signal Processing Charles Robert Giardina, Edward R. Dougherty, 1988 **Image Processing and Mathematical Morphology** Frank Y. Shih, 2017-07-12 In the development of digital multimedia the importance and impact of image processing and mathematical morphology are well documented in areas ranging from automated vision detection and inspection to object recognition image analysis and pattern recognition Those working in these ever evolving fields require a solid grasp of basic fundamentals theory and related applications and few books can provide the unique tools for learning contained in this text *Image Processing and Mathematical Morphology Fundamentals and Applications* is a comprehensive wide ranging overview of morphological mechanisms and techniques and their relation to image processing More than merely a tutorial on vital technical information the book places this knowledge into a theoretical framework This helps readers analyze key principles and architectures and then use the author's novel ideas on implementation of advanced algorithms to formulate a practical and detailed plan to develop and foster their own ideas The book Presents the history and state of the art techniques related to image morphological processing with numerous practical examples Gives readers a clear tutorial on complex technology and other tools that rely on their intuition for a clear understanding of the subject Includes an updated bibliography and useful graphs and illustrations Examines several new algorithms in great detail so that readers can adapt them to derive their own solution approaches This invaluable reference helps readers assess and simplify problems and their essential requirements and complexities giving them all the necessary data and methodology to master current theoretical developments and applications as well as create new ones

Mathematical Morphology and Its Applications to Image and Signal Processing John Goutsias, Luc Vincent, Dan S. Bloomberg, 2006-04-11 Mathematical morphology is a powerful methodology for the processing and analysis of geometric structure in signals and images This book contains the proceedings of the fifth International Symposium on Mathematical Morphology and its Applications to Image and Signal Processing held June 26-28 2000 at Xerox PARC Palo Alto California It provides a broad sampling of the most recent theoretical and practical developments of mathematical morphology and its applications to image and signal processing Areas covered include decomposition of structuring functions and morphological operators morphological discretization filtering connectivity and connected operators morphological shape analysis and interpolation texture analysis morphological segmentation morphological multiresolution techniques and scale spaces and morphological algorithms and applications Audience The subject matter of this volume will be of interest to electrical engineers computer scientists and mathematicians whose research work is focused on the theoretical and practical aspects of nonlinear signal and image processing It will also be of interest to those working in computer vision applied mathematics and computer graphics *Image Processing and Pattern Recognition* Frank Y. Shih, 2010-07-16 A comprehensive guide to the essential principles of image processing and pattern recognition Techniques and applications in the areas of image

processing and pattern recognition are growing at an unprecedented rate. Containing the latest state of the art developments in the field, *Image Processing and Pattern Recognition* presents clear explanations of the fundamentals as well as the most recent applications. It explains the essential principles so readers will not only be able to easily implement the algorithms and techniques but also lead themselves to discover new problems and applications. Unlike other books on the subject, this volume presents numerous fundamental and advanced image processing algorithms and pattern recognition techniques to illustrate the framework. Scores of graphs and examples, technical assistance, and practical tools illustrate the basic principles and help simplify the problems, allowing students as well as professionals to easily grasp even complicated theories. It also features unique coverage of the most interesting developments and updated techniques such as image watermarking, digital steganography, document processing and classification, solar image processing and event classification, 3-D Euclidean distance transformation, shortest path planning, soft morphology, recursive morphology, regulated morphology, and sweep morphology. Additional topics include enhancement and segmentation techniques, active learning, feature extraction, neural networks, and fuzzy logic. Featuring supplemental materials for instructors and students, *Image Processing and Pattern Recognition* is designed for undergraduate seniors and graduate students, engineering and scientific researchers, and professionals who work in signal processing, image processing, pattern recognition, information security, document processing, multimedia systems, and solar physics.

Neural, Morphological, and Stochastic Methods in Image and Signal Processing
Edward R. Dougherty, 1995

Hands-on Morphological Image Processing
Edward R. Dougherty, Roberto A. Lotufo, 2003

Morphological image processing, a standard part of the imaging scientist's toolbox, can be applied to a wide range of industrial applications. Concentrating on applications, this text shows how to analyse the problems and then develop successful algorithms to solve them.

Mathematical Nonlinear Image Processing
Edward R. Dougherty, Jaakko Astola, 2012-12-06

Mathematical Nonlinear Image Processing deals with a fast growing research area. The development of the subject springs from two factors: 1) the great expansion of nonlinear methods applied to problems in imaging and vision and 2) the degree to which nonlinear approaches are both using and fostering new developments in diverse areas of mathematics. *Mathematical Nonlinear Image Processing* will be of interest to people working in the areas of applied mathematics as well as researchers in computer vision. *Mathematical Nonlinear Image Processing* is an edited volume of original research. It has also been published as a special issue of the *Journal of Mathematical Imaging and Vision*, Volume 2, Issue 2/3.

Mathematical Morphology and its Applications to Image and Signal Processing
Henk J.A.M. Heijmans, Jos Roerdink, 1998-05-31

This book contains the proceedings of the International Symposium on Mathematical Morphology and its Applications to Image and Signal Processing IV, held June 3-5, 1998, in Amsterdam, The Netherlands. The purpose of the work is to provide the image analysis community with a sampling of recent developments in theoretical and practical aspects of mathematical morphology and its applications to image and signal processing. Among the areas covered are digitization

and connectivity skeletonization multivariate morphology morphological segmentation color image processing filter design gray scale morphology fuzzy morphology decomposition of morphological operators random sets and statistical inference differential morphology and scale space morphological algorithms and applications Audience This volume will be of interest to research mathematicians and computer scientists whose work involves mathematical morphology image and signal processing

Mathematical Morphology in Image Processing Edward Dougherty, 2018-10-03 Presents the statistical analysis of morphological filters and their automatic optical design the development of morphological features for image signatures and the design of efficient morphological algorithms Extends the morphological paradigm to include other branches of science and mathematics This book is designed to be of interest to optical electrical and electronics and electro optic engineers including image processing signal processing machine vision and computer vision engineers applied mathematicians image analysts and scientists and graduate level students in image processing and mathematical morphology courses

Digital Image Analysis of Microbes M. H. F. Wilkinson, F. Schut, 1998-06-08 Die Entwicklung digitaler Bildverarbeitung gekoppelt an Mikroskopsysteme erm glichte in neuerer Zeit einen zunehmenden Einsatz der Bildanalyse von Mikroben ein wertvolles Hilfsmittel f r das Verst ndnis der Strukturen des Verhaltens und der Diversit t mikrobieller Populationen Dieser aktuelle interdisziplin r angelegte Abri der digitalen Bildverarbeitung wurde von einem internationalen Team von Mikrobiologen Biotechnologen und Computerwissenschaftlern verfa t 04 98

Advances in Signal Processing for Nondestructive Evaluation of Materials X.P. Maldague, 2012-12-06 Non Destructive Evaluation NDE is now playing an increasing role in our modern global economy in security sensitive industries for instance The complexity of the inspection task and either large or limited lot runs now require more operator assisted or fully automated signal processing This book deals with both fields of expertise NDE and signal processing On the signal processing side in the particular context of NDE applications the following topics are discussed sensor fusion signal knowledge representation artificial intelligence fuzzy logic computer vision integration of numeric and non numeric informations parallel decomposition noise processing and calibration of sensor devices as well as reliability of detection Some hardware considerations are introduced as well to discuss platforms on which processing is done On the NDE side applications include advances in holographic interferometry microwave resonance or shearography and also on more traditional NDE techniques such as ultrasonics infrared techniques X ray computed tomography Eddy currents Inverse problems are also discussed This book is required reading for those who already have some experience in one or both fields signal processing and or NDE

Video, Speech, and Audio Signal Processing and Associated Standards Vijay Madisetti, 2018-09-03 Now available in a three volume set this updated and expanded edition of the bestselling The Digital Signal Processing Handbook continues to provide the engineering community with authoritative coverage of the fundamental and specialized aspects of information bearing signals in digital form Encompassing essential background material technical details standards and software the second edition reflects cutting

edge information on signal processing algorithms and protocols related to speech audio multimedia and video processing technology associated with standards ranging from WiMax to MP3 audio low power high performance DSPs color image processing and chips on video Drawing on the experience of leading engineers researchers and scholars the three volume set contains 29 new chapters that address multimedia and Internet technologies tomography radar systems architecture standards and future applications in speech acoustics video radar and telecommunications This volume Video Speech and Audio Signal Processing and Associated Standards provides thorough coverage of the basic foundations of speech audio image and video processing and associated applications to broadcast storage search and retrieval and communications

Process Imaging For Automatic Control David M. Scott, Hugh McCann, 2018-10-03 As industrial processes and their corresponding control models increase in complexity the data provided by traditional point sensors is no longer adequate to ensure product quality and cost effective operation Process Imaging for Automatic Control demonstrates how in process imaging technologies surpass the limitations of traditional monitoring systems by providing real time multidimensional measurement and control data Combined with suitable data extraction and control schemes such systems can optimize the performance of a wide variety of industrial processes Contributed by leading international experts Process Imaging for Automatic Control offers authoritative comprehensive coverage of this new area of process control technology including Basic goals of process modeling and their application to automatic control Direct imaging devices and applications such as machine vision and spatial measurement of flow velocity pressure shear pH and temperature Various techniques hardware implementations and image reconstruction methods for process tomography Image enhancement and restoration State estimation methods State space control system models control strategies and implementation issues Five chapters devoted to case studies and advanced applications From theory to practical implementation this book is the first to treat the entire range of imaging techniques and their application to process control Supplying broad coverage with more than 270 illustrations and nearly 700 cited references it presents an accessible introduction to this rapidly growing interdisciplinary technology

Landmarking and Segmentation of 3D CT Images Shantanu Banik, Rangaraj Rangayyan, Graham Boag, 2022-06-01 Segmentation and landmarking of computed tomographic CT images of pediatric patients are important and useful in computer aided diagnosis CAD treatment planning and objective analysis of normal as well as pathological regions Identification and segmentation of organs and tissues in the presence of tumors are difficult Automatic segmentation of the primary tumor mass in neuroblastoma could facilitate reproducible and objective analysis of the tumor's tissue composition shape and size However due to the heterogeneous tissue composition of the neuroblastic tumor ranging from low attenuation necrosis to high attenuation calcification segmentation of the tumor mass is a challenging problem In this context methods are described in this book for identification and segmentation of several abdominal and thoracic landmarks to assist in the segmentation of neuroblastic tumors in pediatric CT images Methods to identify and segment automatically

the peripheral artifacts and tissues the rib structure the vertebral column the spinal canal the diaphragm and the pelvic surface are described Techniques are also presented to evaluate quantitatively the results of segmentation of the vertebral column the spinal canal the diaphragm and the pelvic girdle by comparing with the results of independent manual segmentation performed by a radiologist The use of the landmarks and removal of several tissues and organs are shown to assist in limiting the scope of the tumor segmentation process to the abdomen to lead to the reduction of the false positive error and to improve the result of segmentation of neuroblastic tumors Table of Contents Introduction to Medical Image Analysis Image Segmentation Experimental Design and Database Ribs Vertebral Column and Spinal Canal Delineation of the Diaphragm Delineation of the Pelvic Girdle Application of Landmarking Concluding Remarks *Intelligent Systems* Cornelius T. Leondes, 2018-10-08 Intelligent systems or artificial intelligence technologies are playing an increasing role in areas ranging from medicine to the major manufacturing industries to financial markets The consequences of flawed artificial intelligence systems are equally wide ranging and can be seen for example in the programmed trading driven stock market crash of October 19 1987 Intelligent Systems Technology and Applications Six Volume Set connects theory with proven practical applications to provide broad multidisciplinary coverage in a single resource In these volumes international experts present case study examples of successful practical techniques and solutions for diverse applications ranging from robotic systems to speech and signal processing database management and manufacturing **Fundamentals of Digital Image Processing** S. Annadurai, 2007 **Computer Vision - ACCV 2006** P. J. Narayanan, 2006 *Intelligent Machine Vision* Bruce Batchelor, Frederick Waltz, 2012-12-06 Intelligent Machine Vision Techniques Implementations algorithm optimization implementation in high speed electronic digital hardware implementation in an integrated high level software environment applications for industrial product quality and process control There are hundreds of illustrations in the book most of them created using the author's PIP software a sophisticated intelligent image processing package A demonstration version of this software as well as numerous examples from the book are available at the authors Web site <http://bruce.cs.cf.ac.uk/bruce/index.html> *Insights Into Mobile Multimedia Communications* David R. Bull, C. Nishan Canagarajah, Andrew R. Nix, 1999 Describes the state of the art in digital multimedia communications This text presents an integrated view of advanced radio systems network architectures and source coding **Computer Analysis of Images and Patterns** Dmitry Chetverikov, Walter Kropatsch, 1993-08-30 This volume constitutes the proceedings of the 5th International Conference on Computer Analysis of Images and Patterns CAIP 93 held in Budapest Hungary in September 1993 Formerly the events in this biennial conference series were thought as a forum where East European researchers and professionals from academia and industry had an opportunity to discuss their results and ideas with Western colleagues active in image processing and pattern recognition Now CAIP 93 has a much more international scope and in the future these conferences will not any longer take place only in East European countries but roam throughout whole Europe Besides invited talks by Belikova Gimel

farb Haralick and Roska the volume contains 114 contributions either presented as lectures or posters and carefully selected by a highly competent international program committee from a total of some 230 submissions thus the book gives a thorough survey on recent research results and their applications in image processing and pattern recognition The proceedings is organized in 20 sections for example on image data structures image processing edges and contours Hough transforms and related methods shape motion 3 D vision character recognition and document processing biomedical applications industrial applications and neural networks

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