

# SpringerBriefs in Computer Science

## *Series editors*

Stan Zdonik, Brown University, Providence, USA  
Shashi Shekhar, University of Minnesota, Minneapolis, USA  
Jonathan Katz, University of Maryland, College Park, USA  
Xindong Wu, University of Vermont, Burlington, USA  
Lakhmi C. Jain, University of South Australia, Adelaide, Australia  
David Padua, University of Illinois Urbana-Champaign, Urbana, USA  
Xuemin (Sherman) Shen, University of Waterloo, Waterloo, Canada  
Borko Furht, Florida Atlantic University, Boca Raton, USA  
V. S. Subrahmanian, University of Maryland, College Park, USA  
Martial Hebert, Carnegie Mellon University, Pittsburgh, USA  
Katsushi Ikeuchi, University of Tokyo, Tokyo, Japan  
Bruno Siciliano, Università di Napoli Federico II, Napoli, Italy  
Sushil Jajodia, George Mason University, Fairfax, USA

For further volumes:

<http://www.springer.com/series/10028>

Ricard Prados · Rafael Garcia  
László Neumann

# Image Blending Techniques and their Application in Underwater Mosaicing

 Springer

Ricard Prados  
Rafael Garcia  
László Neumann  
University of Girona  
Girona  
Spain

ISSN 2191-5768                      ISSN 2191-5776 (electronic)  
ISBN 978-3-319-05557-2            ISBN 978-3-319-05558-9 (eBook)  
DOI 10.1007/978-3-319-05558-9  
Springer Cham Heidelberg New York Dordrecht London

Library of Congress Control Number: 2014934137

© The Author(s) 2014

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed. Exempted from this legal reservation are brief excerpts in connection with reviews or scholarly analysis or material supplied specifically for the purpose of being entered and executed on a computer system, for exclusive use by the purchaser of the work. Duplication of this publication or parts thereof is permitted only under the provisions of the Copyright Law of the Publisher's location, in its current version, and permission for use must always be obtained from Springer. Permissions for use may be obtained through RightsLink at the Copyright Clearance Center. Violations are liable to prosecution under the respective Copyright Law. The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

While the advice and information in this book are believed to be true and accurate at the date of publication, neither the authors nor the editors nor the publisher can accept any legal responsibility for any errors or omissions that may be made. The publisher makes no warranty, express or implied, with respect to the material contained herein.

Printed on acid-free paper

Springer is part of Springer Science+Business Media ([www.springer.com](http://www.springer.com))

*To my mother, R. P.*  
*To Àlex, Laia and Yolanda, R. G.*  
*To my father, L. N.*

# Preface

Underwater surveys have numerous scientific applications in the fields of archeology, geology, and biology, involving tasks such as ancient shipwreck prospection, ecological studies, environmental damage assessment, and detection of temporal changes. When diving at extreme depths or during long periods of time, underwater surveys are nowadays carried out by Underwater Vehicles (UV). These vehicles are often equipped with advanced navigation sensors, including optical cameras. Optical imaging provides short-range, high-resolution visual information about the ocean floor.

Scientists can benefit from these images as they provide, from the cognitive point of view, the most precise and accurate representation of the areas surveyed, enabling a detailed analysis of the structures of interest. The underwater medium adds particular challenges to the image acquisition task, and phenomena such as light attenuation enforce it to be performed as close to the seabed as possible. Hence, optically mapping large seafloor areas can only be achieved by building image mosaics from a set of reduced-area pictures, *i.e.*, *photo-mosaics*. Unfortunately, the seams along image boundaries are often noticeable, due to photometrical and geometrical registration inaccuracies. *Image blending* is the merging step in which those artifacts are minimized. Processing bottlenecks and the lack of medium specific processing tools have restricted underwater photo-mosaics to small areas despite the hundreds of thousands of  $m^2$  that modern surveys can cover. Large underwater photo-mosaics are in increasing demand for the characterization of the seafloor for scientific purposes. Producing these mosaics is difficult due to the challenging nature of the underwater environment and of the image acquisition conditions, including extreme depth, scattering and light attenuation phenomena, and difficulties in vehicle navigation and positioning.

This book proposes strategies and solutions to tackle the problem of building photo-mosaics of very large underwater optical surveys, *i.e.* *Giga-mosaics*, presenting contributions in the image preprocessing, enhancing, and blending steps, and resulting in an improved visual quality of the final photo-mosaic.

First, a comprehensive review of the current and most prominent state-of-the-art mosaicing and blending techniques is provided in [Chap. 3](#), in order to evaluate their application in the underwater imaging context. A classification criterion for the existing methods is presented, based on their main features and performance.

Second, a full approach for large-scale underwater image mosaicing and blending is proposed. In the image preprocessing step, a depth-dependent illumination compensation function is used to solve the nonuniform illumination appearance due to light attenuation. Additionally, if depth information is not available, a depth estimation based on the size of the image projection (once registered) is exploited in different steps of the pipeline. Concerning image enhancement, the image contrast variability due to different acquisition altitudes is compensated using an adaptive contrast enhancement based on an image quality reference selected through a Total Variation (TV) criterion. This criterion is also applied to give a higher priority to the information coming from higher quality images, making the contribution from sharper and more informative images higher than that of contrastless or poorly detailed ones. In the blending step, a graph-cut strategy operating in the image gradient domain over the overlapping regions is proposed. This approach allows finding an adequate seam even if the overlapping images have been acquired with different exposures. A smooth transition around the optimally selected seams is performed in a narrow strip, ensuring the maximum possible sharpness and avoiding double contouring problems. Finally, an out-of-core blending strategy for very large-scale photo-mosaics is presented and tested on real data, generating images surpassing the giga-pixel order, and having, as its only limitation, the maximum size of the tile that can be processed in the computer's memory.

The performance of the proposed approach and the benefits of using blended gigamosaics for interpretation tasks are evaluated in [Chap. 5](#). The results obtained by the proposed method are discussed and compared with other state-of-the-art approaches, using a series of challenging large-scale underwater datasets.

# Contents

<b>1</b>	<b>Introduction</b>	1
1.1	Background	1
1.2	Challenges of Underwater Optical Imaging	4
1.3	Objectives	8
1.4	Outline of the Approach	9
1.5	Contributions	11
1.6	Book Structure	11
	References	12
<b>2</b>	<b>Underwater 2D Mosaicing</b>	15
2.1	Topology Estimation	16
2.2	Image Registration	18
2.2.1	Direct Methods	18
2.2.2	Feature-Based Methods	19
2.3	Motion Estimation	21
2.3.1	Planar Homography	21
2.3.2	Planarity Assumption	22
2.3.3	Outlier Rejection	23
2.4	Global Alignment	24
2.4.1	Global Alignment Methods	25
2.5	Conclusions	29
	References	31
<b>3</b>	<b>State of the Art in Image Blending Techniques</b>	35
3.1	Transition Smoothing Methods	37
3.2	Optimal Seam Finding Methods	42
3.3	Hybrid Methods	45
3.4	Classification	47
3.4.1	Basic Principle	52
3.4.2	Domain	52
3.4.3	Scalability	53

3.4.4	Color and Dynamic Range . . . . .	53
3.4.5	Multiresolution . . . . .	54
3.4.6	Local/Global and Real-Time Operation . . . . .	55
3.4.7	Relevant Visual Performance Criteria . . . . .	55
3.5	Conclusions . . . . .	57
	References . . . . .	57
<b>4</b>	<b>Proposed Framework</b> . . . . .	<b>61</b>
4.1	Input Sequence Preprocessing . . . . .	63
4.1.1	Inhomogeneous Lighting Compensation . . . . .	63
4.1.2	Gradient-Based Image Enhancement . . . . .	67
4.2	Image Registration with Global Alignment . . . . .	69
4.3	Image Contribution Selection . . . . .	70
4.3.1	Image Discarding . . . . .	70
4.3.2	Pixel-Level First-Closest and Second-Closest Maps . . . . .	71
4.3.3	Regions of Intersection . . . . .	72
4.4	Gradient Domain Blending . . . . .	73
4.4.1	Pixel-Level Graph-Cut . . . . .	73
4.4.2	Gradient Blending Over Seam Strips . . . . .	74
4.5	Luminance Recovery from Gradient Fields . . . . .	75
4.6	Tone Mapping . . . . .	75
4.7	Giga-Mosaic Unification . . . . .	75
4.8	Conclusions . . . . .	77
	References . . . . .	78
<b>5</b>	<b>Results</b> . . . . .	<b>79</b>
5.1	Testing Datasets . . . . .	80
5.2	MoMARETO'06 (Dataset #1) . . . . .	81
5.3	MoMAR'08 (Dataset #2) . . . . .	85
5.4	BATHYLUCK'09 (Dataset #3) . . . . .	92
5.5	LaLune'12 (Dataset #4) . . . . .	98
5.6	Temporal Variations . . . . .	101
5.7	Summary . . . . .	102
	References . . . . .	104
<b>6</b>	<b>Conclusions</b> . . . . .	<b>105</b>
	References . . . . .	107



# Acronyms

AUV	Autonomous Underwater Vehicle
BA	Bundle Adjustment
BCM	Brightness Constancy Model
CLAHE	Contrast Limited Adaptive Histogram Equalization
DOF	Degree Of Freedom
DVL	Doppler Velocity Log
EKF	Extended Kalman Filter
GA	Global Alignment
GDIM	Generalized Dynamic Image Model
GPS	Global Positioning System
HDR	High Dynamic Range
HOG	Histogram of Gradients
LBL	Long Baseline
LMedS	Least Median of Squares
MEX	Matlab EXecutable
MST	Minimum Spanning Tree
RANSAC	Random Sample Consensus
ROD	Region of Difference
ROV	Remotely Operated Vehicle
SEF	Seam-Eliminating Function
SIFT	Scale Invariant Feature Transform
SNR	Signal-to-Noise Ratio
SSD	Sum of Squared Differences
SURF	Speeded Up Robust Features
TV	Total Variation
USBL	Ultra Short Baseline
UV	Underwater Vehicle