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Image Blending Techniques and their Application in Underwater Mosaicing

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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

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