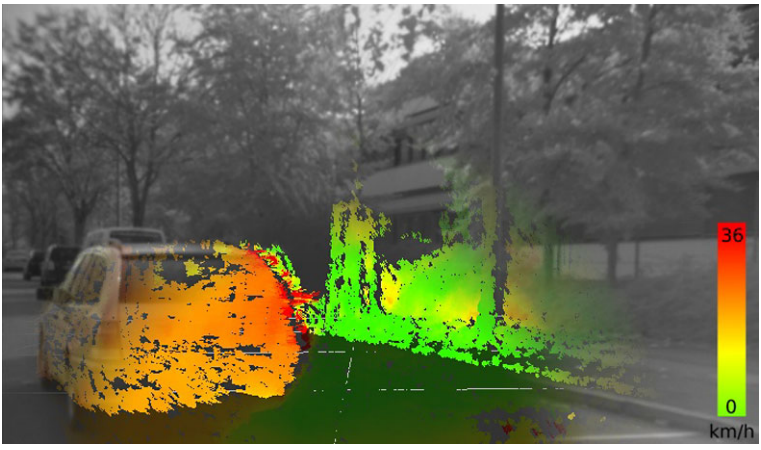
Stereo Scene Flow for 3D Motion Analysis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Springer

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ISBN 978-0-85729-964-2 e-ISBN 978-0-85729-965-9
DOI 10.1007/978-0-85729-965-9
Springer London Dordrecht Heidelberg New York

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Control Number: 2011935628

Cover design: VTeX UAB, Lithuania

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Preface

The estimation of geometry and motion of the world around us from images is at the heart of Computer Vision. The body of work described in this book arose in the context of video-based analysis of the scene in front of a vehicle from two front-facing cameras located near the rear view mirror. The question examined of where things are in the world and how they move over time is an essential prerequisite for a higher-level analysis of the observed environment and for subsequent driver assistance. At the origin of this work is the combination of a strong interest in solving the real-world challenges of camera-based driver assistance and a scientific background in energy minimization methods. Yet, the methods we describe for estimating highly accurate optical flow and scene flow are a central prerequisite in other domains of computer vision where accurate and dense point correspondence between images or between geometric structures observed in stereo-videos is of importance.

Step by step we introduce variational methods which allow us to enhance the image data acquired from two cameras by spatially dense information on the geometric structure and 3D motion of the observed structures. In particular, we introduce variational approaches to optic flow estimation and present a variety of techniques which gave rise to the world's most accurate optic flow method. We introduce a variational approach to estimate scene flow, i.e. the motion of structure in 3D. We discuss metrics for evaluating the accuracy of scene flow estimates. We will also show extensions of scene flow, including flow-based segmentation and the tracking of 3D motion over multiple frames. The latter employs Kalman filters for every pixel of an image assuming linear object motion which results in a stable and dense 3D motion vector field.

The book is written for both novices and experts, covering both basic concepts such as variational methods and optic flow estimation, and more advanced concepts such as adaptive regularization and scene flow analysis.

Much of the work described in this book was developed during the Ph.D. thesis of the first author, both at the University of Bonn and at Daimler Research, Böblingen. Many of these results would not have been possible without the enthusiastic support of a number of researchers. We are particularly indebted to Uwe Franke, Clemens Rabe, and Stefan Gehrig for their work on 6D vision and disparity estimation, to

Thomas Pock in the context of efficient algorithms for optic flow estimation, to Thomas Brox in the parts on variational scene flow estimation, and to Tobi Vaudrey and Reinhard Klette for their research support on residual images and segmentation. We are grateful to our collaborators for their support.

With lane departure warning systems and traffic sign recognition, camera-based driver assistance is gradually becoming a reality. Latest research deals with intelligent systems such as autonomous evasive maneuvers and emergency situation takeover assistance. We hope that this book will help to lay the foundations for higher-level traffic scene understanding, object motion detection, and the development of advanced driver assistance.

Böblingen and Munich, Germany

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List of Notations

$\mathbb{R}$	Real numbers
Ω	Image domain
Ψ_ε	Differentiable approximation of the absolute function $\lvert x\rvert \approx \Psi_\varepsilon(x) = \sqrt{x^2 + \varepsilon^2}$
$\mathbf{F}$	Fundamental matrix
∇I	Spatial gradient of I: $\nabla I\,(x, y, t) = (I_x, I_y)^\top$
I_x, I_y, I_t	Partial derivatives with respect to x, y and t
$\mathcal{N}$	Local neighborhood of a pixel
$\mathcal{N}_4$	4-connected neighborhood
$\mathcal{L}$	Pixel labelling