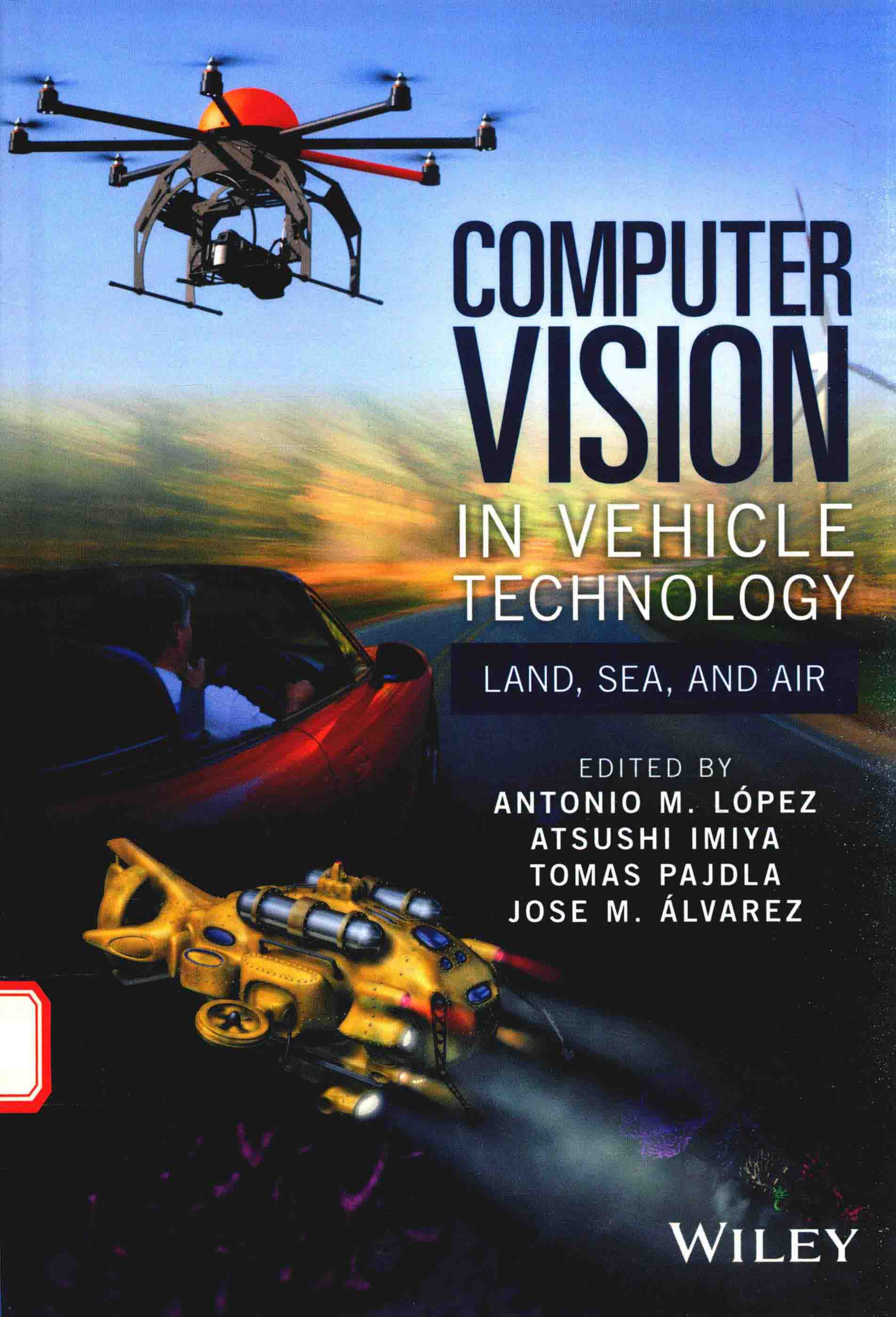

COMPUTER VISION IN VEHICLE TECHNOLOGY

LAND, SEA, AND AIR

EDITED BY

ANTONIO M. LÓPEZ
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Preface

This book was born following the spirit of the *Computer Vision in Vehicular Technology (CVVT)* Workshop. At the moment of finishing this book, the 7th CVVT Workshop CVPR'2016 is being held in Las Vegas. Previous CVVT Workshops include the CVPR'2015 in Boston (http://adas.cvc.uab.es/CVVT2015/), ECCV'2014 in Zurich (http://adas.cvc.uab.es/CVVT2014/), ICCV'2013 in Sydney (http://adas.cvc.uab.es/CVVT2013/), ECCV'2012 in Firenze (http://adas.cvc.uab.es/CVVT2012/), ICCV'2011 in Barcelona (http://adas.cvc.uab.es/CVVT2011/), and ACCV'2010 in Queenstown (http://www.media.imit.chiba-u.jp/CVVT2010/). This implies throughout these years, many invited speakers, co-organizers, contributing authors, and sponsors have helped to keep CVVT alive and exciting. We are enormously grateful to all of them! Of course, we also want to give special thanks to the authors of this book, who kindly accepted the challenge of writing their respective chapters.

He would also like to thank the past and current members of the Advanced Driver Assistance Systems (ADAS) group of the Computer Vision Center at the Universitat Autònoma de Barcelona. He also would like to thank his current public funding, in particular, Spanish MEC project TRA2014-57088-C2-1-R, Spanish DGT project SPIP2014-01352, and the Generalitat de Catalunya project 2014-SGR-1506. Finally, he would like to thank NVIDIA Corporation for the generous donations of different graphical processing hardware units, and especially for their kind support regarding the ADAS group activities.

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Atsushi Imiya was supported by IMIT Project *Pattern Recognition for Large Data Sets* from 2010 to 2015 at Chiba University, Japan.

Jose M. Álvarez was supported by the Australian Research Council through its Special Research Initiative in Bionic Vision Science and Technology grant to Bionic Vision Australia. The National Information Communications Technology Australia was founded by the Australian Government through the Department of Communications and the Australian Research Council through the ICT Center of Excellence Program.

The book is organized into seven self-contained chapters related to CVVT topics, and a final short chapter with the overall final remarks. Briefly, in Chapter 1, there is a quick overview of the main ideas that link computer vision with vehicles. Chapters 2–7 are more specialized and divided into two blocks. Chapters 2–4 focus on the use of computer vision for the self-navigation of the vehicles. In particular, Chapter 2 focuses on land (autonomous cars), Chapter 3 focuses on air (micro aerial vehicles), and Chapter 4 focuses on sea (underwater robotics). Analogously, Chapters 5–7 focus on the use of computer vision as a technology to solve specific applications beyond self-navigation. In particular, Chapter 5 focuses on land (ADAS), and Chapters 6 and 7 on air and sea, respectively. Finally, Chapter 8 concludes and points out new research trends.

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Abbreviations and Acronyms

ACC	adaptive cruise control
ADAS	advanced driver assistance system
AUV	autonomous underwater vehicle
BA	bundle adjustment
BCM	brightness constancy model
BoW	bag of words
CAN	controller area network
CLAHE	contrast limited adaptive histogram equalization
COTS	crown of thorns starfish
DCT	discrete cosine transforms
DOF	degree of freedom
DVL	Doppler velocity log
EKF	extended Kalman filter
ESC	electronic stability control
FCA	forward collision avoidance
FEM	finite element method
FFT	fast Fourier transform
FIR	far infrared
FLS	forward-looking sonar
GA	global alignment
GDIM	generalized dynamic image model
GLCM	gray level co-occurrence matrix
GPS	global positioning system
GPU	graphical processing unit
HDR	high dynamic range
HOG	histogram of gradients
HOV	human operated vehicle
HSV	hue saturation value
IR	infrared
KPCA	kernel principal component analysis
LBL	long baseline

LBP	local binary patterns
LCA	lane change assistance
LDA	linear discriminant analysis
LDW	lane departure warning
LHC	local homogeneity coefficient
LKS	lane keeping system
LMedS	least median of squares
MEX	MATLAB executable
MLS	moving least squares
MR	maximum response
MST	minimum spanning tree
NCC	normalized chromaticity coordinates
NDT	normal distribution transform
NIR	near infrared
OVV	online visual vocabularies
PCA	principal component analysis
PDWMD	probability density weighted mean distance
PNN	probabilistic neural network
RANSAC	random sample consensus
RBF	radial basis function
ROD	region of difference
ROI	region of interest
ROV	remotely operated vehicle
SDF	signed distance function
SEF	seam-eliminating function
SIFT	scale invariant feature transform
SLAM	simultaneous localization and mapping
SNR	signal-to-noise ratio
SSD	sum of squared differences
SURF	speeded up robust features
SVM	support vector machine
TJA	traffic jam assist
TSR	traffic sign recognition
TV	total variation
UDF	unsigned distance function
USBL	ultra short base line
UUV	unmanned underwater vehicle
UV	underwater vehicle

Contents

1

Computer Vision in Vehicles

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This chapter is a brief introduction to academic aspects of computer vision in vehicles. It briefly summarizes basic notation and definitions used in computer vision. The chapter discusses a few visual tasks as of relevance for vehicle control and environment understanding.

1.1 Adaptive Computer Vision for Vehicles

Computer vision designs solutions for understanding the real world by using cameras. See Rosenfeld (1969), Horn (1986), Hartley and Zisserman (2003), or Klette (2014) for examples of monographs or textbooks on computer vision.

Computer vision operates today in *vehicles* including cars, trucks, airplanes, unmanned aerial vehicles (UAVs) such as multi-copters (see Figure 1.1 for a quadcopter), satellites, or even autonomous driving rovers on the Moon or Mars.

In our context, the *ego-vehicle* is that vehicle where the computer vision system operates in; *ego-motion* describes the ego-vehicle's motion in the real world.

1.1.1 Applications

Computer vision solutions are today in use in manned vehicles for improved safety or comfort, in autonomous vehicles (e.g., robots) for supporting motion or action control, and also for misusing UAVs for killing people remotely. The UAV technology has also good potentials for helping to save lives, to create three-dimensional (3D) models of

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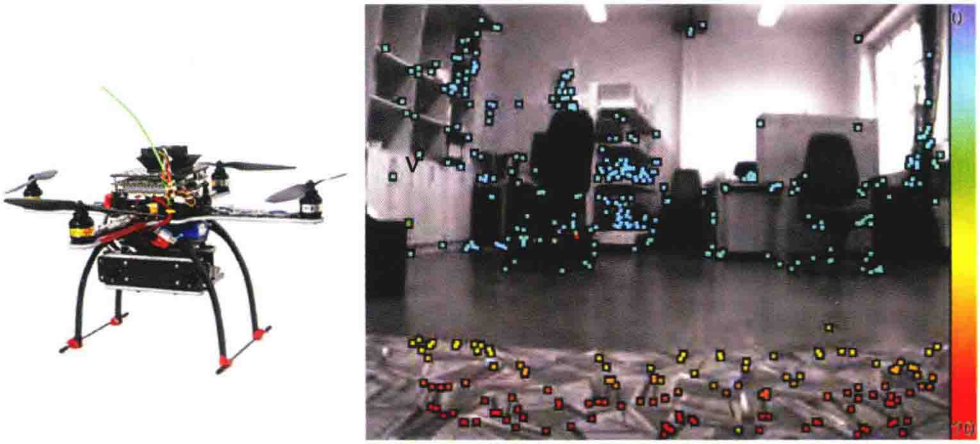

(a) (b)

Figure 1.1 (a) Quadcopter. (b) Corners detected from a flying quadcopter using a modified FAST feature detector. Courtesy of Konstantin Schauwecker

the environment, and so forth. Underwater robots and unmanned sea-surface vehicles are further important applications of vision-augmented vehicles.

1.1.2 Traffic Safety and Comfort

Traffic safety is a dominant application area for computer vision in vehicles. Currently, about 1.24 million people die annually worldwide due to traffic accidents (WHO 2013), this is, on average, 2.4 people die *per minute* in traffic accidents. How does this compare to the numbers Western politicians are using for obtaining support for their "war on terrorism?" Computer vision can play a major role in solving the true real-world problems (see Figure 1.2). Traffic-accident fatalities can be reduced by controlling traffic flow (e.g., by triggering automated warning signals at pedestrian crossings or intersections with bicycle lanes) using stationary cameras, or by having cameras installed in vehicles (e.g., for detecting safe distances and adjusting speed accordingly, or by detecting obstacles and constraining trajectories).

Computer vision is also introduced into modern cars for improving driving comfort. Surveillance of blind spots, automated distance control, or compensation of unevenness of the road are just three examples for a wide spectrum of opportunities provided by computer vision for enhancing driving comfort.

1.1.3 Strengths of (Computer) Vision

Computer vision is an important component of intelligent systems for vehicle control (e.g., in modern cars, or in robots). The Mars rovers "Curiosity" and "Opportunity" operate based on computer vision; "Opportunity" has already operated on Mars for

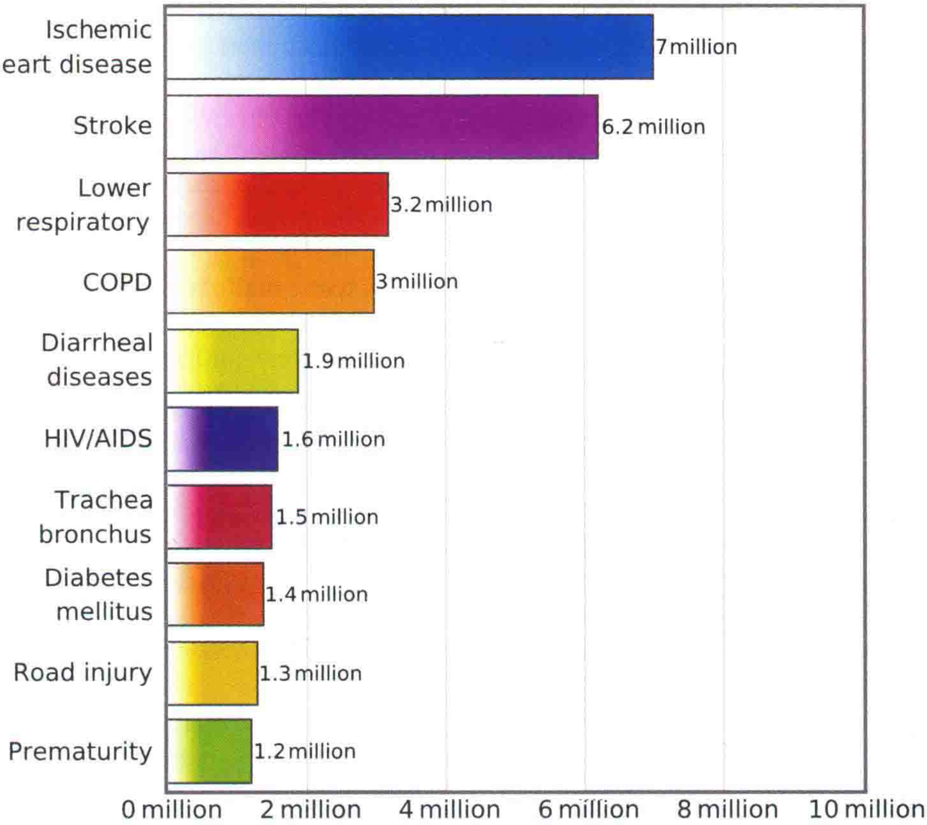

Figure 1.2 The 10 leading causes of death in the world. Chart provided online by the World Health Organization (WHO). Road injury ranked number 9 in 2011

more than ten years. The visual system of human beings provides a proof of existence that vision alone can deliver nearly all of the information required for steering a vehicle. Computer vision aims at creating comparable automated solutions for vehicles, enabling them to navigate safely in the real world. Additionally, computer vision can also work constantly "at the same level of attention," applying the same rules or programs; a human is not able to do so due to becoming tired or distracted.

A human applies accumulated knowledge and experience (e.g., supporting intuition), and it is a challenging task to embed a computer vision solution into a system able to have, for example, intuition. Computer vision offers many more opportunities for future developments in a vehicle context.

1.1.4 Generic and Specific Tasks

There are *generic visual tasks* such as calculating distance or motion, measuring brightness, or detecting corners in an image (see Figure 1.1b). In contrast, there are *specific visual tasks* such as detecting a pedestrian, understanding ego-motion, or calculating the *free space* a vehicle may move in safely in the next few seconds. The borderline between generic and specific tasks is not well defined.

Solutions for generic tasks typically aim at creating one self-contained *module* for potential integration into a complex computer vision system. But there is no general-purpose corner detector and also no general-purpose stereo matcher. *Adaptation* to given circumstances appears to be the general way for an optimized use of given modules for generic tasks.

Solutions for specific tasks are typically structured into multiple modules that interact in a complex system.

Example 1.1.1 Specific Tasks in the Context of Visual Lane Analysis *Shin et al. (2014) review visual lane analysis for driver-assistance systems or autonomous driving. In this context, the authors discuss specific tasks such as "the combination of visual lane analysis with driver monitoring..., with ego-motion analysis..., with location analysis..., with vehicle detection..., or with navigation...." They illustrate the latter example by an application shown in Figure 1.3: lane detection and road sign reading, the analysis of GPS data and electronic maps (e-maps), and two-dimensional (2D) visualization are combined into a real-view navigation system (Choi et al. 2010).*

Figure 1.3 Two screenshots for real-view navigation. Courtesy of the authors of Choi et al. (2010)

1.1.5 Multi-module Solutions

Designing a multi-module solution for a given task does not need to be more difficult than designing a single-module solution. In fact, finding solutions for some single modules (e.g., for motion analysis) can be very challenging. Designing a multi-module solution requires: