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Óscar Martínez Mozos

Semantic Labeling of Places with Mobile Robots

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To my family and friends
A mi familia y amigos

Editorial Foreword

By the dawn of the new millennium, robotics has undergone a major transformation in scope and dimensions. This expansion has been brought about by the maturity of the field and the advances in its related technologies. From a largely dominant industrial focus, robotics has been rapidly expanding into the challenges of the human world. The new generation of robots is expected to safely and dependably co-habitat with humans in homes, workplaces, and communities, providing support in services, entertainment, education, healthcare, manufacturing, and assistance.

Beyond its impact on physical robots, the body of knowledge robotics has produced is revealing a much wider range of applications reaching across diverse research areas and scientific disciplines, such as: biomechanics, haptics, neurosciences, virtual simulation, animation, surgery, and sensor networks among others. In return, the challenges of the new emerging areas are proving an abundant source of stimulation and insights for the field of robotics. It is indeed at the intersection of disciplines that the most striking advances happen.

The goal of the series of *Springer Tracts in Advanced Robotics* (STAR) is to bring, in a timely fashion, the latest advances and developments in robotics on the basis of their significance and quality. It is our hope that the wider dissemination of research developments will stimulate more exchanges and collaborations among the research community and contribute to further advancement of this rapidly growing field.

The monograph written by Óscar Martínez Mozos is a contribution in the area of mobile robot navigation and perception, which has been receiving a great deal of attention by the research community in the latest few years. The contents expand the author's doctoral dissertation and are focused on the problem of assigning semantic labels to sensor data. A number of solutions inherited from pattern recognition and classification are introduced to enable a mobile robot to categorize places in typical indoor environments, such as a room or a corridor. Results are accompanied by a rich set of experiments, revealing a promising outlook toward the application to a

wide range of mobile robots and service settings, such as elderly care, guiding, office and domestic assistance, and inspection.

Yet another STAR volume on mobile robots, a very fine addition to the series!

Naples, Italy
October 2009

Bruno Siciliano
STAR Editor

Foreword

Service robots that are able to operate autonomously and to interact with their users are one of the major research goals in robotics. In previous years there has been a tremendous progress in the area of robot navigation and perception. However, the question of how to bridge the gap between such subsymbolic and symbolic tasks like planning or interaction has remained an open research question.

In this book, Óscar Martínez Mozos addresses the problem of assigning semantic labels to sensor data. He considers problems like labeling places in the environment, extracting topological representations from geometric maps, utilizing semantic labels for exploration and navigation as well as for human-robot interaction. All approaches have been validated on real robotic systems and on data gathered with real robots.

To my opinion, this book describes an approach that builds the basis of a roadmap towards getting from subsymbolic sensations to symbolic representations. It describes methods for the direct interpretation and also for the temporal and spatial integration. I truly believe that it will be the basis for plenty of follow-up research projects that build upon the approaches described in this work and take us closer to semantically embedded robots.

Freiburg, Germany
September 2009

Wolfram Burgard

Preface

During the last years there has been an increasing interest in the area of service robots. Under this category we find robots working in tasks such as elderly care, guiding, office and domestic assistance, inspection, and many more.

Service robots usually work in indoor environments designed for humans, with offices and houses being some of the most typical examples. These environments are typically divided into places with different functionalities like corridors, rooms or doorways. The ability to learn such semantic categories from sensor data enables a mobile robot to extend its representation of the environment, and to improve its capabilities. As an example, natural language terms like *corridor* or *room* can be used to indicate the position of the robot in a more intuitive way when communicating with humans.

This book presents several approaches to enable a mobile robot to categorize places in indoor environments. The categories are indicated by terms which represent the different regions in these environments. The objective of this work is to enable mobile robots to perceive the spatial divisions in indoor environments in a similar way as people do. This is an interesting step forward to the problem of moving the perception of robots closer to the perception of humans.

Many approaches introduced in this book come from the area of pattern recognition and classification. The applied methods have been adapted to solve the specific problem of place recognition. In this regard, this work is a useful reference to students and researchers who want to introduce classification techniques to help solve similar problems in mobile robotics. In addition, the data sets corresponding to most of the experiments in the book can be found at

http://www.informatik.uni-freiburg.de/~omartine/place_data_sets.html

This book was possible thanks to the help and support of many people. First of all, I would like to thank Wolfram Burgard for giving me the opportunity to work under his supervision. Many thanks to Aleš Leonardis for his interest in my work. And thanks to Henrik Christensen for supporting this book. Special thanks to friends and

colleagues that contributed to this book: Cyrill Stachniss, Axel Rottmann, Rudolph Triebel, Kai Arras, Hendrik Zender, and Patric Jensfelt.

I would like to thank the people providing the data sets which I used in my experiments. Cyrill Stachniss provided the map of building 79 at the University of Freiburg. Steffen Gutmann provided the map of building 52 at the University of Freiburg. Dieter Fox provided the map of the interior of the Intel Research Lab in Seattle. Finally, Andrew Howard provided the map of the building in Virginia.

This work is the result of my stay as a PhD student in the Autonomous Intelligent Systems Laboratory in Freiburg. I would like to thank the staff of this laboratory for their support.

During my stay in Freiburg I met many interesting people and made very good friends. I would like to thank all of them for making my life in this city more comfortable.

In addition, I would like to thank Justin Bachmann for helping me with the proofreading of the book.

Mamá, papá, hermano y resto de familia, vosotros sois los más importantes.

Alicante, Spain
September 2009 Óscar Martínez Mozos

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Notation

α	weak classifier weight
ε	weak classifier error
τ	feature transformation
$bel(\cdot)$	belief
f	feature
$h(\cdot)$	weak classifier
$p(k)$	probability of class k
x	example
y_k	label of class k
z	robot observation
A	set of features from the raw beams of an observation z
B	set of features from a polygonal approximation $\mathrm{Pol}(z)$ of an observation z
C^+	confidence value for a positive classification
C^-	confidence value for a negative classification
D	weight distribution over the training examples
E	set of edges in a graph, $\mathrm{E} \subseteq \mathrm{V} \times \mathrm{V}$
G	undirected graph
$H(\cdot)$	strong classifier
K	number of elements in Y
L	total number of features representing an example x
N	number of training examples
$\mathrm{Ne}(\cdot)$	neighborhood of a node in a graph
P	probability distribution over places
O	set of influence weights of nodes
$\mathrm{Pol}(z)$	polygonal approximation of an observation z
Q	set of cliques in a graph
R	compatibility coefficients
S	separability criterion
T	number of final weak classifiers in $H(\cdot)$
V	set of vertices in a graph
X	set of examples
Y	set of classes
Z	set of observations