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Pierre Lamon

3D-Position Tracking and Control for All-Terrain Robots

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To Mati, Sophie and the baby

Foreword

At the dawn of the new millennium, robotics is undergoing a major transformation in scope and dimension. From a largely dominant industrial focus, robotics is rapidly expanding into the challenges of unstructured environments. Interacting with, assisting, serving, and exploring with humans, the emerging robots will increasingly touch people and their lives.

The goal of the new 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 Pierre Lamon is the second the series devoted to tracking and control of robots in rough terrain. Research in this area has been mainly focused on 2D localization, on the assumption of flat surfaces. Whenever the rover has to climb over obstacles in cluttered environments, accurate 3D position tracking is crucial for both autonomous navigation and obstacle negotiation, as discussed in the introductory chapter. The trade-off between scientific and technical solutions makes this volume unique in the wide field of autonomous mobile robotics. The finalization of the approach on a real rover experimental platform allows a clear understanding of the influence of mechanical design, locomotion control and sensing on the pose tracking problem.

Remarkably, the monograph is based on the author's doctoral thesis, which received the prize of the Sixth Edition of the EURON Georges Giralt PhD Award devoted to the best PhD thesis in Robotics in Europe. A very fine addition to the Series!

Naples, Italy
December 2007

Bruno Siciliano
STAR Editor

Preface

During the first year of my doctoral thesis I went to Carnegie Mellon University for an internship. The goal was to implement the Mars Autonomy software[1] on Shrimp, a six wheeled rover with extended climbing capabilities. At that time, Shrimp had limited sensing capabilities and was only able to travel autonomously for about ten meters in a flat and simple environment. The robot couldn't reach farther goals because it rapidly lost track of its position. Thus, I decided to focus my research on position tracking in order to extend the range of autonomous navigation.

At that time, most of the research works in all-terrain rover navigation assumed flat environments and addressed 2D localization. Even though 2D localization is sufficient for many applications, the extension to 3D is necessary in cluttered environment, when the rover has to climb over the encountered obstacles. In such conditions, accurate 3D position tracking is crucial for both autonomous navigation and obstacle negotiation. The subject of my thesis and, *a fortiori* this book, was clear: 3D-position tracking and control for all-terrain robots.

Methodology

Autonomous mobile robotics is a fascinating field of research that involves technical and scientific domains. Thus, the research community working in this field is composed of people with very different backgrounds. One finds for example mathematicians, physicians, computer scientists, engineers and biologists. It is interesting to note that each researcher has his or her own definition of an autonomous mobile robot and has an individual way to address a given problem. However, two main categories of approaches can be distinguished i.e., the top-down and the bottom-up. One or the other is favored depending on the researcher's scientific and technical background. The top-down approach consists in developing a theoretical formulation of the problem and proposing a solution based on mathematical models. Although such a solution can be analyzed with respect to e.g. optimality and mathematical complexity, it does not necessarily

[1] The Mars Autonomy project: http://www.frc.ri.cmu.edu/projects/mars

work for the real application. Indeed, it often occurs that the models do not fully capture the reality or that they cannot be applied because they make use of unknown parameters. A failure to apply a model happens when the abstraction level is too high and when the technical constraints are not fully considered during the development phase. On the other hand, the bottom-up approach starts from a real application and proposes pragmatic solutions to given problems. The risk with such an approach is to tailor solutions in an incremental way, that is, to patch the system as problems arise. Such a reactive development favors the use of heuristics that may limit the system's performance and reliability.

The methodology used throughout this book is an attempt to reconcile the top-down and the bottom-up approaches and to avoid their respective traps. Even though the development was driven by the application, the bottom-up approach was not particularly favored. Thus, simple but valid heuristics were proposed only when modeling was not applicable. On the other hand, the technical constraints were considered during the modeling phases to avoid the generation of inapplicable models. In other words, the methodology used in this book tries to make the best tradeoff between scientific and technical solutions.

Acknowledgment

This work is an adventure during which I met many different people ready to help and to act as a source of inspiration. First of all, I am grateful to my advisor, Roland Siegwart, for convincing me to do a doctoral thesis at the Autonomous Systems Laboratory. All this has been possible thanks to his positive attitude, mentorship and support.

During the thesis, I had the chance to spend several months in other labs. Each time, the experience was very positive and stimulating. The first exchange was at CMU, were I discovered the world of linux and autonomy applied to rough terrain rovers. I would like to thank Reid Simmons for agreeing to supervise my work, Sanjiv Singh and Dennis Strelow for their help related to visual motion estimation, and Bart Nabbe and Jianbo Shi for their good advice. The next two exchanges took place at the Laboratoire d'Analyse et d'Architecture des Systèmes (LAAS-CNRS). In particular, I would like to thank Simon Lacroix, Anthony Mallet and Raja Chatila for their help and for having hosted me in excellent conditions.

Most of the student projects related to this research provided very good results, which helped to validate the theory through experiments with SOLERO. I would like to thank Ambroise Krebs for his excellent masters thesis, which enabled the development of a new approach to slip minimization in rough terrain. Also, I am grateful to Stéphane Michaud for the development of the mechanical structure of SOLERO, Martin Nyffenegger for the nice remote control interface, Benoît Dagon for the mechanical design of the panoramic vision system and Gabriel Paciotti for the stereovision rig.

The help of my colleagues was invaluable, and enabled me to develop the various systems discussed in this book. In particular, I would like to thank Grégoire Terrien and Michel Lauria for their expert advice related to the mechanical

aspects, Agostino Martinelli for the mathematics, Daniel Burnier, Ralph Piguet and Gilles Caprari for the electronics and finally Rolf Jordi and Frédéric Pont for the questions related to informatics. The positive atmosphere in the lab provided favorable conditions for efficient and constructive work. Special thanks to Marie-José Pellaud, Nicola Tomatis, Daniel Burnier and my office-mate Gilles Caprari for their psychological support. I'm grateful to everybody in the lab for the great time I've spent during these four years.

Thanks also to the members of my thesis committee, Simon Lacroix, Paolo Fiorini and Bertrand Merminod, for their careful reading of the thesis and for their constructive feedback.

Lausanne, Switzerland *Pierre Lamon*
December 2007

Contents