# Embedded Robotics

Thomas Bräunl

# EMBEDDED ROBOTICS

## Mobile Robot Design and Applications with Embedded Systems

Third Edition

With 305 Figures and 32 Tables

Springer

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# PREFACE

The EyeBot controller and mobile robots have evolved over more than a decade. This book gives an in-depth introduction to embedded systems and autonomous mobile robots, using the EyeBot controller (EyeCon) and the EyeBot mobile robot family as application examples.

This book combines teaching and research material and can be used for courses in Embedded Systems as well as in Robotics and Automation. We see labs as an essential teaching and learning method in this area and encourage everybody to reprogram and rediscover the algorithms and systems presented in this book.

Although we like simulations for many applications and treat them in quite some depth in several places in this book, we do believe that students should also be exposed to real hardware in both areas, embedded systems and robotics. This will deepen the understanding of the subject area and of course create a lot more fun, especially when experimenting with small mobile robots.

The original goal for the EyeBot project has been to interface an embedded system to a digital camera sensor (EyeCam), process its images locally in realtime for robot navigation, and display results on a graphics LCD. All of this started at a time before digital cameras came to the market – in fact the EyeBot controller was one of the first “embedded vision systems”.

As image processing is always hungry for processing power, this project requires somewhat more than a simple 8-bit microprocessor. Our original hardware design used a 32-bit controller, which was required for keeping up with the data delivered by the image sensor and for performing some moderate image processing on board. Our current design uses a fast state-of-the-art embedded controller in combination with an FPGA as hardware accelerator for low-level image processing operations. On the software application level (application program interface), however, we try to stay compatible with the original system as much as possible.

The EyeBot family includes several driving robots with differential steering, tracked vehicles, omnidirectional vehicles, balancing robots, six-legged walkers, biped android walkers, and autonomous flying and underwater robots. It also comprises simulation systems for driving robots (EyeSim) and underwater robots (SubSim). EyeBot controllers are used in several other projects, with and without mobile robots. We use stand-alone EyeBot controllers for lab experiments in a course in Embedded Systems as part of the Electrical Engineering, Computer Engineering, and Mechatronics curriculum, while we and numerous other universities use EyeBot controllers together with the associated simulation systems to drive our mobile robot creations.

## Acknowledgments

While the controller hardware and robot mechanics were developed commercially, several universities and numerous students contributed to the EyeBot software collection. The universities involved in the EyeBot project are as follows:

- Technical University München (TUM), Germany
- University of Stuttgart, Germany
- University of Kaiserslautern, Germany
- Rochester Institute of Technology, USA
- The University of Auckland, New Zealand
- The University of Manitoba, Winnipeg, Canada
- The University of Western Australia (UWA), Perth, Australia

The author thanks the following students, technicians, and colleagues: Gerrit Heitsch, Thomas Lampart, Jörg Henne, Frank Sautter, Elliot Nicholls, Joon Ng, Jesse Pepper, Richard Meager, Gordon Menck, Andrew McCandless, Nathan Scott, Ivan Neubronner, Waldemar Spädt, Petter Reinholdtsen, Birgit Graf, Michael Kasper, Jacky Baltes, Peter Lawrence, Nan Schaller, Walter Bankes, Barb Linn, Jason Foo, Alistair Sutherland, Joshua Petitt, Axel Waggershauser, Alexandra Unkelbach, Martin Wicke, Tee Yee Ng, Tong An, Adrian Boeing, Courtney Smith, Nicholas Stamatiou, Jonathan Purdie, Jippy Jungpakdee, Daniel Venkitachalam, Tommy Cristobal, Sean Ong, and Klaus Schmitt.

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## Contributions

A number of colleagues and former students contributed to this book. The author thanks everyone for their effort in putting the material together.

Jacky Baltes The University of Manitoba, Winnipeg, contributed to the section on PID control

Adrian Boeing UWA, coauthored the chapters on the evolution of walking gaits and genetic algorithms, and contributed to the section on SubSim and car detection

Mohamed Bourgou TU München, contributed the section on car detection and tracking

Christoph Braunschädel FH Koblenz, contributed data plots to the sections on PID control and on/off control

Michael Drtil FH Koblenz, contributed to the chapter on AUVs

Louis Gonzalez UWA, contributed to the chapter on AUVs

Birgit Graf Fraunhofer IPA, Stuttgart, coauthored the chapter on robot soccer

Hiroyuki Harada Hokkaido University, Sapporo, contributed the visualization diagrams to the section on biped robot design

Simon Hawe TU München, reimplemented the ImprovCV framework

Yves Hwang UWA, contributed to the chapter on genetic programming

Philippe Leclercq UWA, contributed to the section on color segmentation

James Ng UWA, coauthored the sections on probabilistic localization, Bug algorithms, and Brushfire algorithm

Joshua Petitt UWA, contributed to the section on DC motors

Klaus Schmitt Univ. Kaiserslautern, coauthored the section on the RoBIOS operating system

Torsten Sommer TU München, contributed the graphics part of the neural network demonstration program

Alistair Sutherland UWA, coauthored the chapter on balancing robots

Nicholas Tay DSTO, Canberra, coauthored the chapter on map generation

Daniel Venkitachalam UWA, coauthored the chapters on genetic algorithms and behavior-based systems and contributed to the chapter on neural networks

Bernhard Zeisl TU München, coauthored the section on lane detection

EyeSim Implemented by Axel Waggershauser (V5) and Andreas Koestler (V6), UWA, Univ. Kaiserslautern, and FH Giessen

SubSim Implemented by Adrian Boeing, Andreas Koestler, and Joshua Petitt (V1), and Thorsten Rühl and Tobias Bielohlawek (V2), UWA, FH Giessen, and Univ. Kaiserslautern

## Additional Material

Hardware and mechanics of the “EyeCon” controller and various robots of the EyeBot family are available from INROSOFT and various distributors:

**`http://inrosoft.com`**

All system software discussed in this book, the RoBIOS operating system, C/C++ compilers for Linux and Windows/Vista, system tools, image processing tools, simulation system, and a large collection of example programs are available free from the following website:

**`http://robotics.ee.uwa.edu.au/eyebot/`**

## Third Edition

Almost five years after publishing the original version, we have now completed the third edition of this book. This edition has been significantly extended with new chapters on CPUs, robot manipulators and automotive systems, as well as additional material in the chapters on navigation/localization, neural networks, and genetic algorithms. This not only resulted in an increased page count, but more importantly in a much more complete treatment of the subject area and an even more well-rounded publication that contains up-to-date research results.

This book presents a combination of teaching material and research contents on embedded systems and mobile robots. This allows a fast entry into the subject matter with an in-depth follow-up of current research themes.

As always, I would like to thank all students and visitors who conducted research and development work in my lab and contributed to this book in one form or another.

All software presented in this book, especially the RoBIOS operating system and the EyeSim and SubSim simulation systems can be freely downloaded from the following website:

**`http://robotics.ee.uwa.edu.au`**

Lecturers who adopt this book for a course can receive a full set of the author’s course notes (PowerPoint slides), tutorials, and labs from this Web site. And finally, if you have developed some robot application programs you would like to share, please feel free to submit them to our Web site.

Perth, Australia, August 2008 — Thomas Bräunl

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