Renaissance Robotics:

embedding multithreaded real-time feedback
into mobile robots and cyber-physical systems

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Preface

Leveraging emerging technologies for advanced cellphones and computer graphics, a vast assortment of small powerful single-board computers (SBCs), operating at very low power, are readily available today for coordinating small robotic systems, with remarkable new SBCs being announced often. At the same time, an increasing number of important applications demand creative small-scale robotic solutions, including:

- security & patrol,
- remote inspection & repair,
- mobility enhancement,
- food preparation & delivery,
- elder care & monitoring,
- nursing & feeding assistance,
- biomedical devices & prosthetics,
- minimally invasive surgery,
- pharmaceutical testing & development,
- concierge service & shopping assistance,
- precision agriculture:
  - water/pesticide/fertilizer application,
  - weed removal,
  - fruit & vegetable harvesting,
- package delivery,
- personal transportation,
- HVAC for smart grids,
- floor cleaning & laundry,
- scientific exploration,
- environmental monitoring,
- STEM education & toys.

Additionally, real-world deployments of robust AI/ML algorithms, capable of complex contextual decision making in highly consequential settings, are becoming increasingly capable for smart cars, autonomous flying taxis, and other large-scale safety-critical applications, while advanced wifi, cellular, and satellite-based internet access are becoming faster and more readily available, respectively, within buildings, across both urban and rural areas, and over the entire planet.

An important missing link for the rapid development and deployment of small-scale robotic systems leveraging such existing and emerging components, and across this growing set of needs, is the availability of easy-to-use and easy-to-extend solutions for **motor control** and the attendant high-current **voltage regulation**. In this text, we thus endeavor to fill this void by introducing a new ecosystem of cross-platform, open-design (open hardware + open-source software), self-contained, ARM-based carrier boards, dubbed **Berets**, that readily attach to (a) the 5V power, and 5V TTL logic, 40-pin header on Raspberry Pi (RPi) and compatible motherboards (MBs), including both a large number of RPi clones as well as GPU compute platforms from NVIDIA, (b) the 12V power, and 1.8V CMOS logic, 40-pin header on MBs in the 96boards CE format, including the Qualcomm Robotics RB5 platform, or (c) other small MBs via standard SPI connections, or for standalone operation.

Chapter 5 of this text provides a detailed datasheet for this new **Beret** ecosystem, including an extensible Arduino-style family of small daughterboards for further expansion options, dubbed **Beret Shields**. Concomitant with the presentation of this ecosystem, Chapter 4 introduces a uniquely extensible connector standard dubbed **Recon** that coordinates the (substantial) portfolio of connectivity options on the Berets. The rest of Part I puts these new developments in context, with surveys of some of the current and emerging technologies that enable the development of advanced mobile robots and cyberphysical systems, including discussions of:

- how today's powerful and remarkably efficient SBCs work (Chapter 1),
- essential modern programming environments and languages for embedded applications (Chapter 2),
- the dominant short-range and long-range (wired and wireless) communication protocols (Chapter 3), and
- the sensors, actuators, and interfaces available that enable new game-changing applications (Chapter 6).

Part I does not include any differential equations or advanced mathematics, and should be accessible to all "makers" (in high school and beyond) who want to significantly upgrade their technological portfolios.

Part II then provides brief introductions to some of the essential theory used in modern robotics, including:

- Linear Error-Correcting Codes (Chapter 7),
- Robot Kinematics & Dynamics (Chapter 8),
- ODE Simulation (Chapter 9),
- Signals & Systems (Chapter 10),
- Circuits (Chapter 11),
- Classical Control (Chapter 12), and
- Motion Planning (Chapter 13).

A key skill that separates curious "makers" from professional "roboticists" is the *analysis* that facilitates minimalist, power-efficient, cost-effective, safe, and responsive cyber-physical design. The core material in Part II (at the level of university undergraduate courses on each of the respective subjects, often taught in the traditional engineering fields of ME, AE, EE, or CS), though by no means exhaustive, form some of the essential theoretical foundations for performing such analysis-based design of robotic systems. A companion volume by the same author, *Numerical Renaissance* (*NR*, occasional forward references to which are made in this text), delves much deeper (at the level of university graduate courses) into the key theories and algorithms in many related areas.

Finally, Part III motivates some ideas related to robotic system design, development, and integration, including brief discussions of

- Open vs Proprietary Development Models (Chapter 14),
- Crowd Funding vs Venture Capital (Chapter 15),
- Computer Aided Design & Manufacturing (CAD/CAM) (Chapter 16), and
- various Design Paradigms (Chapter 17).

The text concludes (in Chapter 18) with a detailed case study of a fascinating educational robotics platform, dubbed myMiP, demonstrating multithreaded multirate feedback, as depicted on the book cover.

Codes and exercises related to each chapter are available at

https://github.com/tbewley/RR

Note that all codes in the Renaissance Robotics codebase are Copyright 2021 by Thomas Bewley, and distributed under the BSD 3-Clause License. Please help us improve this effort by submitting bug fixes, broken links, typos, etc. via the above site.

Part I

Technology