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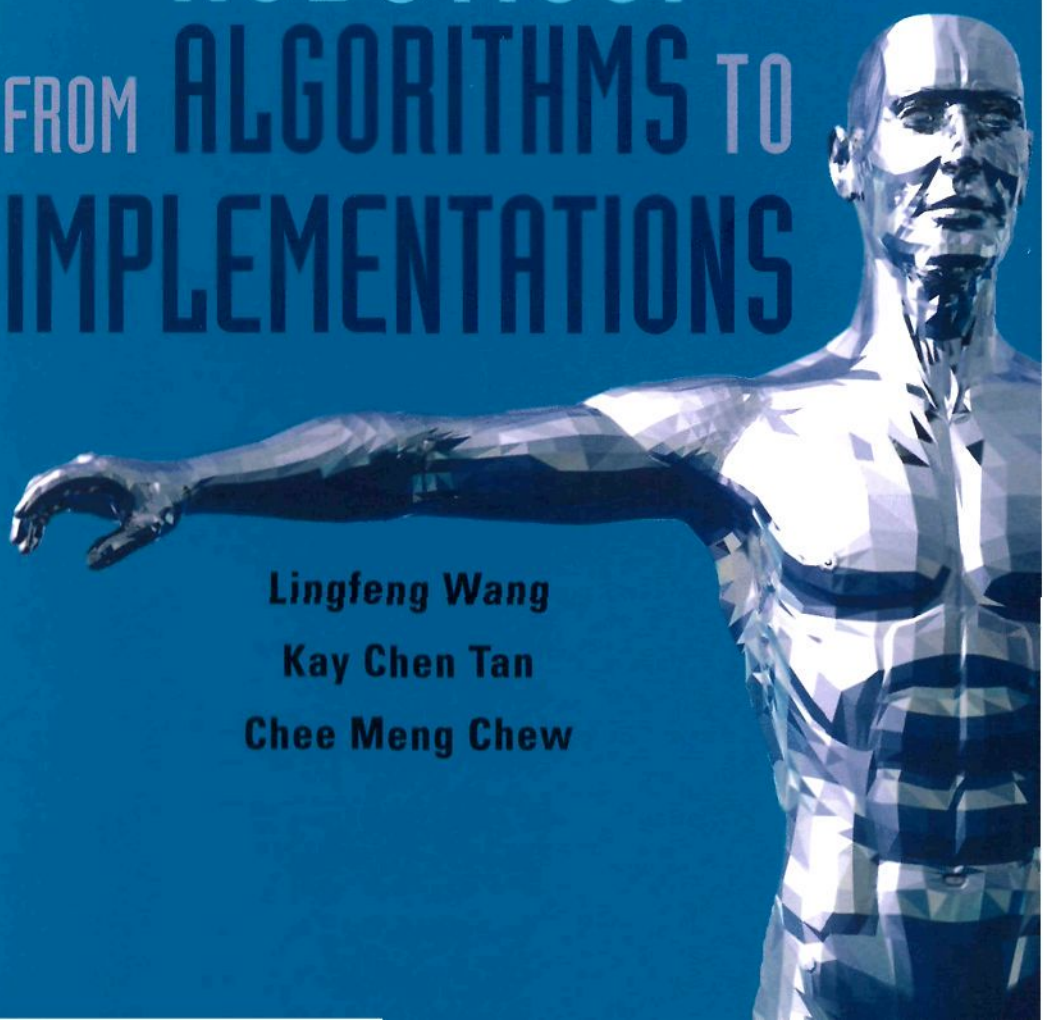
EVOLUTIONARY ROBOTICS: FROM ALGORITHMS TO IMPLEMENTATIONS



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To our families, for their love and patience.

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Preface

Modern robotics has moved from the industrial manufacturing environment to human environment for service and entertainment in the recent few years. The human environment is typically unstructured and quite often ever-changing, the robot is required to be capable of independently learning the dynamic environment as well as continuously adjusting its behavior to accomplish the desired tasks during its execution. It should be able to capture the properties of the environment effectively and make suitable decisions accordingly to properly deal with the current situation in real-time. In order to accomplish the desired tasks, mobile robots should have a certain level of intelligence to deal with the uncertainties occurred the environment that they are operating in. For instance, if a mobile robot is required to keep track of a moving object, it needs to determine by itself the movement of the target and plan its appropriate path to closely follow the target. Meanwhile, the robot may be asked to execute other tasks such as obstacle avoidance during its motion. However, the pre-programmed robots can not accomplish such tasks adaptively since they have no ability to handle the real operating situations in a smart fashion.

In the design of intelligent artifacts, robot engineers have always been inspired by nature. For instance, the design of these intelligent systems has being influenced significantly by the physiology of natural evolution. The simplicity and robustness of biological species are the highly desired characteristics for autonomous robotic systems. Like their biological counterparts, autonomous mobile robots should be able to perceive both static and dynamic aspects of the external environment and adjust their behaviors accordingly in order to adapt to it. Fortunately, nature provides invaluable inspirations for the design of robotic system capable of exhibiting certain intelligent behaviors. Inspired by the biological solution, we attempt to

build a variety of intelligent behaviors for the autonomous mobile robot. In the research reported in this book, a thorough literature review, followed by representative and extensive experiment studies, illustrates the effectiveness of the biologically inspired approach to intelligent robotic controller design. The emphasis of this book is placed on the artificial intelligence based evolutionary robotics.

There are two major methods in controller design for intelligent robots, one of which is hardware-based design and another is software-based (i.e., algorithm-based) design. For the hardware-based robotic controller design, robotic controller is derived at the evolvable hardware level, which is a novel and salient set of integrated circuits capable of reconfiguring their architectures using artificial evolution techniques. In this book, two chapters are dedicated to the evolvable hardware based robotics. Software (or algorithm)-based design is more conventional with respect to the hardware-based one. In this designs, the emphasis is put on the design and implementation of software-based robotic controllers. The controllers are usually compiled and burned in the processor which is embedded in the autonomous robotic systems. In this book, five real-world examples of software-based robotic controller designs are discussed in detail.

Structure of the Book. The primary motivation for this book is to discuss the application of biologically-inspired approaches in the design and development of autonomous intelligent robotic systems. A variety of techniques were employed to implement the different robotic behaviors. Except for the evolvable hardware based evolutionary robotics, other design techniques used for autonomous intelligent robotic systems are also discussed in the book, which include fuzzy logic, evolutionary computing, reinforcement learning, and so forth. The book presents a very detailed review of the state-of-the-art in the domain of evolutionary robotics and some case studies on practical design and implementation of intelligent robotic systems are also fleshed out. The overall book structure is arranged in the following way: In the first chapter, the basic concepts regarding artificial evolution and evolutionary robotics are introduced, and then a variety of successful applications of artificial evolution in autonomous robot navigation along the dimension of artificial evolution adopted are surveyed and discussed. Open issues and future research in this field are also presented. The second chapter surveys the application of evolvable hardware in evolutionary robotics, which is an emerging research field concerning the development of evolvable robot controller at the hardware level in order to adapt to dynamic changes in the environment. The context of evolvable hardware

and evolutionary robotics is reviewed respectively, and a few representative experiments in the field of robotic hardware evolution are presented. As an alternative to conventional robotic controller designs, the potentialities and limitations of the evolvable hardware based robotic system are discussed and summarized. The third chapter presents the design and real-time implementation of an evolvable hardware based autonomous robot navigation system using intrinsic evolution. Distinguished from the traditional evolutionary approaches based on software simulation, an evolvable robot controller at the hardware gate-level that is capable of adapting dynamic changes in the environments is implemented. The fourth chapter presents the design and implementation of an autonomous robot navigation system for intelligent target collection in dynamic environments. A feature-based multi-stage fuzzy logic sensor fusion system is developed for target recognition, which is capable of mapping noisy sensor inputs into reliable decisions. The robot exploration and path planning are based on a grid map oriented reinforcement path learning system, which allows for long-term predictions and path adaptation via dynamic interactions with physical environments. The fifth chapter presents a new approach of task-oriented developmental learning for humanoid robotics. It is capable of setting up multiple tasks representation automatically using real-time experiences, which enables a robot to handle various tasks concurrently without the need of predefining the tasks. The sixth chapter discusses a general control architecture for bipedal walking which is based on a divide-and-conquer approach. Based on the architecture, the sagittal-plane motion-control algorithm is formulated using a control approach known as virtual model control. A reinforcement learning algorithm is used to learn the key parameter of the swing leg control task so that stable walking can be achieved. In the seventh chapter, a genetic algorithm tuned fuzzy logic controller is proposed for bipedal walking control implementation. The basic structure of fuzzy logic controller is constructed based on the linear inverted pendulum model. Genetic algorithm is implemented to search and optimize the fuzzy logic controller parameters. The eighth chapter investigates the application of genetic algorithm as an optimization tool to search and optimize key parameter in the walking controlling of a humanoid robot. Virtual model control is employed as a control framework where ankle gain plays an important part in regulating forward velocity during walking. The final chapter concludes the book and discusses the possible future research directions in this field.

Readers. The communities of intelligent control and autonomous robotics in both academia and industry should find that this book is useful

and able to provide an up-to-date view of the fields. It is hoped that this book can serve as a good reference for further study as well as provide a different perspective on robot control. The utility of the entire AI-based approach is however open to debate and ultimately will only show its strength if it stands the rest of time, or, at least in the short term, provides sufficiently effective and convincing solutions to current challenging real-world problems. The book is likely to be useful to people in the areas of intelligent systems, autonomous robots, intelligent robotics, or what has been called "evolutionary robotics" as indicated in the book title. While this book will likely be of most interest to electrical engineers, mechanical engineers, and computer scientists, it may also be interesting to persons in other fields such as biological sciences due to its interdisciplinary feature.

The reader is assumed to be familiar with the fundamental knowledge in algorithm, software, and hardware designs. In industry, practitioners, evolutionary designers, and hardware designers will probably like the research results reported in this book. In academia, teachers and students can utilize any individual chapters as the reference materials for their lectures and studies in evolutionary algorithms, evolutionary robotics, and evolvable hardware.

Acknowledgments. Many people deserve special acknowledgment for their help throughout the entire duration of research, book writing, and production. First, the assistance from Dr. Christopher J. Harris, the Editor-in-Charge of World Scientific Series in Robotics and Intelligent Systems, is highly appreciated. We also wish to thank the people who communicated with us in World Scientific Publishing Inc. and Imperial College Press, especially to Mr. Steven Patt (Desk Editor) and Mrs. Katie Lydon (Editorial Assistant), for all their kind help in the acquisition, editing, and production processes of this book. For the preparation of the first three chapters, we would like to express great thanks to Dr. K. Ide in the Applied AI Systems, Inc., Canada and Dr. A. Thompson at the University of Sussex, U. K. for their invaluable comments and encouragement at the stage of evolvable hardware study. Our special thanks go to O. Carmona, S. Legon, and A. Griffith in the K-team, Inc., Switzerland for their timely technical support. Dr. T. Hirst at the Open University in U. K. and Dr. H. Sakanashi at the ETL of Japan also helped us a lot by providing useful literature. All of the work reported in the first five chapters was conducted in the Center for Intelligent Control (CIC), Department of Electrical and Computer Engineering, National University of Singapore. The work of R. Xian, Y. J. Chen, P. Xiao, and X. Liu laid solid foundations for the research

reported in these chapters. For Chapter 6, the authors wish to thank Dr. Gill A. Pratt for his comments provided to this research. For Chapter 7, the authors would like to thank Min Du for helping to carry out the implementation of the simulation and Weiwei Huang for helping to organize the data. For Chapter 8, the authors wish to thank Professor G.-S. Hong for his valuable comments given to this project. We also like to thank the graduate students, H.-N. Ho and T. Sateesh, for working on the simulation implementation, designing the robot's hardware, and writing the draft report for this research. We are also indebted to many colleagues and friends for their assistance and advice. Our friends have stood by and encouraged us when our productivity waned. Finally, we wish to thank our families for their ever-present encouragement and for the moral and practical support given over the years before and throughout this endeavor. We dedicate this book to them.

The readers are encouraged to send us their questions arisen in reading the book. Any problems and comments can be directed to the first author at l.f.wang@ieee.org. We hope readers enjoy the volume! Go forth and produce!

L. F. Wang, K. C. Tan, and C. M. Chew

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Contents

Chapter 1

Artificial Evolution Based Autonomous Robot Navigation

Modern robots are required to carry out work in unstructured dynamic human environments. In the recent decades, the application of artificial evolution to autonomous mobile robots to enable them to adapt their behaviors to changes of the environments has attracted much attention. As a result, an infant research field called evolutionary robotics has been rapidly developed that is primarily concerned with the use of artificial evolution techniques for the automatic design of adaptive robots. As an innovative and effective solution to autonomous robot controller design, it can derive adaptive robotic controllers capable of elegantly dealing with continuous changes in unstructured environments in real time. In the chapter, the basic concepts regarding artificial evolution and evolutionary robotics are introduced, and then a variety of successful applications of artificial evolution in autonomous robot navigation along the dimension of artificial evolution adopted are surveyed and discussed. Open issues and future research in this field are also presented.

1.1 Introduction

Early robots were nothing more than clever mechanical devices that performed simple pick-and-place operations. Nowadays robots are becoming more sophisticated and diversified so as to meet the ever-changing user requirements. The robots are developed to perform more precise industrial operations, such as welding, spray painting, and simple parts assembly. However, such operations do not really require the robot to have intelligence and behave like human beings since the robots are simply programmed to perform a series of repetitive tasks. If anything interferes with the prespecified task, the robot cannot work properly anymore, since it is not