Neural Systems for Robotics

Edited by

Omid Omidvar

Patrick van der Smagt

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Preface

What place does a book containing a set of papers on a specific research topic have in the midst of the current deluge of publications and preprints, most of which are available free of charge and without leaving one's desk? It is exactly this ever-increasing amount of publications which more and more necessitates the reviewing process, and asks for a digest of the published material. That is what we set out to do.

When putting together a book on neural networks and robotics, papers with different angles, views, and themes have to be somehow selected and combined so that a coherent volume emerges. Naturally, a full review of the field is impossible in any manageable number of pages. In this volume you will find lengthy papers giving an extensive overview of the field, and describing one or more approaches in detail. Thus a picture of the whole research field, where robotics and neural networks are combined, emerges.

The chapters in this book are logically selected and grouped. The path that is followed goes through four stages:

1. Research inspired by biological systems at the behavioral level

2. Control of robot arms using artificial neural networks

3. Simulation of and inspiration by biological neural systems

4. Control and navigation of mobile robots using artificial neural networks.

The first three chapters describe neural networks which simulate biological systems at the behavioral level. The third chapter ends with neural control of a robot arm; this topic is picked up by the subsequent—overview—chapter, followed by an in-depth study in this field. The next three chapters are focused on biological neural systems, and describe applications in the navigation of mobile robots. This theme is covered in detail in the final two chapters.

Evaluating a biological system at the behavioral level, Chapter 1, "Neural Network Sonar as a Perceptual Modality for Robotics," by Itiel Dror, Mark Zagaeski, Damien Rios, and Cynthia Moss, describes a neural network which approximates echo-locating behavior of the big brown bat, *Eptesicus fuscus*. Using previous studies of this bat, a neural system is introduced which can determine speed of movement using a single echolocation only, referring back to studies which show that bats differentiate between different wingbeat rates of insects. The results presented in this chapter provide a good basis for the use of echolocation in robotic systems.

In Chapter 2, "Dynamic Balance of a Biped Walking Robot," by Thomas Miller III and Andrew Kun, a neural system is used to have a robot learn to walk. The approach is unique: Instead of using analyses of walking behavior of biological systems, the neural network-driven robot uses feedback from force sensors mounted on the undersides of the feet, as well as from accelerometers mounted on the body. The learning behavior that is exhibited typically resembles that of biological systems which learn to walk.

A technique for the control of robot manipulators is introduced in Chapter 3, "Visual Feedback in Motion," by Patrick van der Smagt and Frans Groen. This research is also inspired by a biological system at the behavioral level. Using studies of the gannet from the family of Sulidæ, sequences of two-dimensional visual signals are interpreted to guide a monocular robot arm in three-dimensional space, without using models of the visual sensor nor the robot arm.

Exploration of the control of robot arms is continued in Chapter 4, "Inverse Kinematics of Dextrous Manipulators," by David DeMers and Kenneth Kreutz-Delgado. The chapter gives an overview of neural and nonneural methods to solve the inverse kinematics problem: Given an end-effector position and orientation, how should one move a robot arm (in a most efficient way) to reach that position/orientation?

The theoretically inclined Chapter 5, "Stable Manipulator Trajectory Control Using Neural Networks," by Yichuang Jin, Tony Pipe, and Alan Winfield, describes neural network approaches for trajectory following of a robot arm. The key issue here is how to improve the accuracy of the followed trajectory when the dynamic model of the robot arm is inaccurate.

Studies of sensory motor control in biological organisms and robots are presented in Chapter 6, "The Neural Dynamics Approach to Sensory-Motor Control," by Paolo Gaudiano, Frank Guenther, and Eduardo Zalama. It extensively discusses neural network models developed at Boston University's Center for Adaptive Systems. The neural models are used in two applications: trajectory following of a mobile robot, and controlling the motor skills required for speech reproduction using auditory-orosensory feedback.

Biomorphic robots are discussed in Chapter 7, "Operant Conditioning in Robots," by Andreas Bühlmeier and Gerhard Manteuffel. In their overview chapter, they discuss neural systems which maintain homeostasis for (mobile) robot systems. After discussing neural learning systems with neurophysiological backgrounds, a survey of several implementations on mobile robots, which have to learn to navigate between obstacles, is given.

In Chapter 8, "A Dynamic Net for Robot Control," by Bridget Hallam, John Hallam, and Gillian Hayes, a neural model, designed for explaining various learning phenomena from animal literature, is used to control a mobile robot.

The navigation of mobile robots using artificial neural networks is covered in Chapter 9, "Neural Vehicles," by Ben Kröse and Joris van Dam. The authors make the distinction between reactive navigation, planned navigation in known environments, and map building from sensor signals.

In the final chapter, "Self-Organization and Autonomous Robots," Jukka Heikkonen and Pasi Koikkalainen describe the use of self-organizing maps for reactive control of mobile robots.

Putting together a book like this requires the cooperation of a large group of people. The anonymous reviewers remain unmentioned; so, first of all, the patience and cooperation of the authors has to be acknowledged. Of great importance was the support, inspiration, and help of the Institute of Robotics and System Dynamics at the German Aerospace Research Establishment (DLR) in Oberpfaffenhofen; especially the unprecedented support of prof. dr. Gerd Hirzinger has been key in the production of this volume. Last but not least, none of this would be there without Britta Platt, whose support is without end. This volume is dedicated to her.

Patrick van der Smagt, *Editor*
Omid Omidvar, *Series Editor*

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Neural Network Sonar as a Perceptual Modality for Robotics

Itiel E. Dror
Mark Zagaeski
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Cynthia F. Moss

ABSTRACT Sonar (SOund NAvigation Ranging) employs a transmitter to generate an acoustic signal and a receiver to register echoes returning from objects in the path of the sound beam. Sonar has been extensively used in robotics for object detection, ranging, and avoidance. However, such applications represent a limited use of sonar, as they do not exploit the full range of information carried by the sonar echoes. This is evidenced by the remarkable perceptual capabilities of echolocating bats, who demonstrate that sonar can convey detailed information about the environment. In this chapter we present data showing that a relatively simple neural network sonar system can perform complex pattern recognition tasks, and propose that sonar has great potential usefulness for robotics. We suggest that sonar has applications in robotics not only for detection of objects and ranging, but also for gathering detailed information about these objects. We begin the chapter with a brief description of the current use of sonar in robotics, and a short tutorial on the bat biosonar system. We then present neural network sonar systems that recognize faces and objects independent of perceptual variations, and a neural network sonar system that can recognize the speed of a moving target based on a single echo.

1.1 Use of Sonar in Robotics

Mobile robots need to navigate in an unpredictable and hazardous world. They must be able to detect obstacles in their path and avoid them. Sonar has been a useful tool for obstacle avoidance; using an ultrasonic ranging system (originally developed by Polaroid for focusing cameras), robots can easily detect the presence of obstacles. The system transmits an ultrasonic pulse from an electrostatic transducer and measures the time it takes for an echo to return. If no echo returns within a given time window, then the robot may continue along its path unobstructed. If, however, there is an