## **Self-Reconfigurable Robots**

An Introduction

Kasper Stoy David Brandt David J. Christensen

The MIT Press Cambridge, Massachusetts London, England © 2010 Massachusetts Institute of Technology

All rights reserved. No part of this book may be reproduced in any form by any electronic or mechanical means (including photocopying, recording, or information storage and retrieval) without permission in writing from the publisher.

For information about special quantity discounts, please email special\_sales@mitpress.mit.edu

This book was set in Times New Roman on 3B2 by Asco Typesetters, Hong Kong. Printed and bound in the United States of America.

Library of Congress Cataloging-in-Publication Data

Stoy, Kasper, 1973–
Self-reconfigurable robots : an introduction / Kasper Stoy, David Brandt, and David J. Christensen.
p. cm. — (Intelligent robotics and autonomous agents series)
Includes bibliographical references and index.
ISBN 978-0-262-01371-0 (hardcover : alk. paper) 1. Robotics. 2. Robots. I. Brandt, David, 1979–
II. Christensen, David J. III. Title.
TJ211.S794 2010
629.8'92—dc22 2009021060

10 9 8 7 6 5 4 3 2 1

## Index

3D-Unit, 15, 18, 78, 79, 84

A\*. 121 Active robustness, 32 Actuators, 55-64 strength, 62 types, 63 Adaptability, 32 Alignment of connectors, 47, 49, 65-66 Applications, potential, 22 Asimov, Isaac, 11 ATRON, 3-6, 18, 78, 79, 84 chain-based motion of, 60 complexity of, 37 meta-module, 106 module autonomy, 56 power-sharing, 89 size of configuration space, 104 Attractor, 130–133 Autonomy, movement, 56-57 Balance, maintaining, 152-154 Battery power, 89 Behavior adaptation, 176 Behavior mode, 178 Behavior selection, 177 Behavior-based robotics, 173, 175 Bipartite, 51–53 Brushed DC motor, 63 Brushless DC motor, 63

Camera sensor, 92 for docking, 140 Capek, Josef, 9 Catoms, 69, 78, 79, 84 energy, 89 CEBOT, 12 Cellular robot, 11–13 Centralized communication, 85 Central pattern generators, 168 Chain-based motion, 57–60

Bus, communication, 85

Chain-type, 4, 42 Cheapness, 8, 33–35 Chobie, 20, 48, 61, 78, 79, 84 ckBot, 2, 34 Claytronics, 24 Cluster-flow locomotion, 47, 146-147 Collective actuation, 169 Communication Infrastructure, 83-84 Computing Infrastructure, 83-84 Complexity, 36–37 Configuration representation, 134-138 Connectivity, 100-101, 138 Connectors, 64-74 desirable characteristics, 65 mechanical, 69-71 magnetic, 67-69 electrostatic, 71-74 CONRO, 15, 16, 42, 78, 79, 84 connector of, 69-70 docking, 56 locomotion of, 43, 166, 167 self-reconfiguration, 7 Constrained optimization, 169 Constructor robot, self-reconfiguration using, 76 Contingency challenge, 1 Contraction (optimization algorithm), 120 Controller-limited set of configurations, 107 Controllers, role of, 27-29 Cooperative actuation, 169 Coordinate attractor, 130 CPG, 168 Crystalline robot, 15, 19, 46, 78, 79, 84

Design goals, 29–36 Distance metrics. *See* Metrics Distributed actuator array, 169 Distributed search, 123 Docking, 139–140 Dynamically reconfigurable, 7–8

Environment, 27–29 Electrostatic connectors, 71, 75

Electronics, 83-94 Energy, 89 Features of self-reconfigurable robots, 8, 29-36 Filtering (optimization algorithm), 120 Fracta, 13-15, 45, 78, 79, 84 connectors, 67-69 energy, 89 self-reconfiguration, 61 Functional (characteristics of solutions), 39 Gait control tables, 158-159 Gear-type unit, 20, 78, 79, 84 Genderless connector, 65-66 Global communication, 87–88 Gradient attractor, 130-133 Growth (self-reconfiguration control), 136–138, 147 - 151Herd robots, 21–22 Heterogeneous modules, 54-55 Heterogeneous self-reconfiguration, 154 Hierarchical search, 121 History of self-reconfigurable robots, 9-20 Hollow configurations, 99-100

dealing with, 107 Hormone-based control, 159–162 Hungarian method, 119 Hybrid, 5, 49 Hybrid communication, 88–89 HYDRON, 74

I-Cubes, 15, 78, 79, 84, 121 Informed search, 117–121 Infrared communication, 87 Initiator selection, 162 Intermediate configurations, 109 Inverse kinematics, 140, 169 Iterative improvement (Search), 120

Kinematics, 57, 140, 169

Lattice structure, 49-53 Lattice-type, 45-48 Laws of robotics, 11 Leader selection. See Initiator selection Linear actuator, 59 Local communication, 86-87 Local minima, 100 dealing with, 133 Local rules, 129-130, 136-138, 146 Locomotion, control of, 146–149, 157–169 cluster-flow, 146-149 dynamic configuration, 146-149 fixed configuration, 157-169 M-TRAN, 17-20, 50, 78, 79, 84 chain-based motion of, 59 connectors, 67-68, 70, 72 module autonomy, 56

self-reconfiguration, 50, 61 submodule-based design, 53 Magnetic connectors, 67-69 Manipulation, 169 Mechanical connectors, 69-71 Merging. See Docking Meta-module, 54, 103-106 control. 139 in search, 121-122, 123 Metamorphic (characteristic), 37-38 Metamorphic (robot), 13-14, 78, 79, 84 Metrics (search), 118-120 Micro-Unit, 15, 17, 78, 79, 84 Modular, 5–7 Module, 3–8 Module Geometry, 49–53 Molecube, 18, 78, 79, 84 Molecule (robot), 15, 17, 78, 79, 84 connectors, 70-71 self-reconfiguration, 61 submodules, 53 Morphing materials, 25 Morphing production lines, 1, 3, 23 Morphology, 28-29 Motion constraints, 97-99 reduce, 102-107, 109 Multimode communication, 88-89 Multirobot systems, 76

Neighborhood, 103-107

On-line search, 123 Optimal assignment metric, 119 Overcrowding, 102 Overlap metric, 119

Pack robots, 21 Pacman algorithm, 123 Passive robustness, 32 Phase automata, 164 Planning, 113–123 PolyBot, 15, 16, 78, 79, 84 chain-based motion of, 57–59 connectors, 70 Polymorphic, 37 PolyPod, 13, 78, 79, 84 locomotion, 158–160 Power sharing, 89 Power supply, external, 89 Processor, 83–84 Proximity sensor, 91, 92

Randomness in search, 120–121 Randomness in self-reconfiguration, 128–129 Recharge, 89 Reconfigurable, 7 Recruitment, 133–134 Redundancy, 33, 35

## Index

Responsive, 38-39 Robust, 32–33 Role-based control, 162-166 Roombot, 53–54, 78, 79 submodules, 53 Rotational actuators, 59 RRT-connect, 121 Rule-based control. See Local rules Scaffolding, 107 Scalability, 38 Search. 113-123 Search algorithms, 120-121 Search space, 114–117 representation, 114-115 Self-assembly, 76 Self-reconfigurable robots, 3-8 existing systems, 78, 79, 84 Self-reconfiguration, 7 chain-type, 42 definitions, 96 heterogeneous, 154 lattice-type, 45-48 problems, 97-102 simplifications, 102-110 Self-replicating robots, 76 Sensors, 90-91 Serial manipulator, 169 Shape memory alloy, 63 Simplicity (characteristic), 36-37 Simulated annealing, 120 Simulator, 183-184 SINGO connector, 71 Solid configurations, 99-100 Space-filling, 51 Stepper DC motor, 63 Stigmergy, 85-86 Stochastic self-assembly, 76 Submodules, 53-54 Subsymbolic communication, 85-86 SuperBot, 18, 78, 79, 84 chain-based motion of, 59-60 locomotion, 31 module autonomy, 56 project, 1-3, 23 robot, 18 self-reconfiguration, 61-62 Surface-covering, 51 Swarm robots, 21-22 Synchronization, 159, 162, 163-164, 166, 168 Tactile sensor, 91 Telecube, 15, 19, 78, 79, 84 connectors, 67-68 Tilt sensor, 91, 178 Topology, discover, 86 Torque sensor, 91

Transition rule sets. *See* Local rules Types of self-reconfigurable robots, 42–49 Unified simulator for self-reconfigurable robots, 183 Uniform configuration, 103–107 Unisex connector, 65–66 USSR, 183

Versatility, 29-31

Water-flow locomotion. *See* Cluster-flow locomotion Wired communication, 87 Wireless communication, 85, 88