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Satoshi Murata and Haruhisa Kurokawa

Self-Organizing Robots

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Foreword

Robotics is undergoing a major transformation in scope and dimension. From a largely dominant industrial focus, robotics is rapidly expanding into human environments and vigorously engaged in its new challenges. Interacting with, assisting, serving, and exploring with humans, the emerging robots will increasingly touch people and their lives.

Beyond its impact on physical robots, the body of knowledge robotics has produced is revealing a much wider range of applications reaching across diverse research areas and scientific disciplines, such as: biomechanics, haptics, neurosciences, virtual simulation, animation, surgery, and sensor networks among others. In return, the challenges of the new emerging areas are proving an abundant source of stimulation and insights for the field of robotics. It is indeed at the intersection of disciplines that the most striking advances happen.

The *Springer Tracts in Advanced Robotics (STAR)* is devoted to bringing to the research community the latest advances in the robotics field on the basis of their significance and quality. Through a wide and timely dissemination of critical research developments in robotics, our objective with this series is to promote more exchanges and collaborations among the researchers in the community and contribute to further advancements in this rapidly growing field.

The monograph by Satoshi Murata and Haruhisa Kurokawa is an English translation from a recently appeared book in Japanese on self-organizing mechanical systems. This is a relatively new area of research focusing on the realization of machines and robots, made to have a certain structure and functions, which are indeed capable to adapt to unexpected situations, such as a misuse or a break-down, and ultimately reorganize themselves. As such, the book has a wide interest for scholars in the area of autonomous distributed systems, modular design and biologically-inspired robotics.

Rich in examples and case studies, deep in the discussion of various issues in the implementation and instrumentation of self-organizing mechanical systems, this volume ambitiously aims at inspiring the designers of the next generation of robots. A very fine addition to the STAR series!

Naples, Italy
August 2011

Bruno Siciliano
STAR Editor

Preface*

The notion of *self-organization* has recently been used in a variety of areas. It refers to the phenomenon in which an entity produces its own organization or structure by itself, just as biological organisms do. For example, seeds sown in the ground will sprout and leaves will grow. Then flowers will bloom, fruit will form, and finally seeds are reproduced. By simply putting the seed into the ground, it spontaneously *becomes* these things without any outside guidance. What an intriguing and fascinating process! What, then, about machines? There has never been a machine that developed by itself from a seed. Machines are built from many parts in factories using external forces. Instructions are given from the outside for each step of assembly. In short, machines are *made* to have a certain structure.

These days, the machines we need in our everyday life have become more and more complicated. It now has become difficult to grasp every detail of these machines, and every detail of the mechanisms at work. Moreover, when those machines break down or are used in unexpected manners, the behavior of the machines can become unpredictable or in fact completely useless. In situations like this, one might hope that the machine would somehow adapt to the situation by reorganizing itself. This is where the notion of *self-organizing* mechanical systems comes in. It means changing from machines that are *made* to have a certain structure and functions, to those that *become* reorganized in a desired way.

Engineers have been learning from biology for a very long time. The drawing of flying machines by Leonardo da Vinci shows that research fields such as biomechanics and biomimetics have their origins back at least to that time. However, in order to create a machine that *becomes* properly organized, it is not sufficient to copy the appearance or the superficial mechanisms of biological organisms. It is necessary to understand the architecture and mechanisms behind the organisms that enable them to function. The theme of this book is to examine the feasibility of creating such artificial systems, namely *self-organizing robots*, the title of this book, within the limitations of current mechanical engineering. We have to consider how to construct such robots, and have to find possible applications for them. Robotics in general has many different aspects such as dynamics, fabrication, control, electronic implementation, and software. In this book, in addition to

* This book is an English translation of "Jiko-soshiki kikai sisutemu no sekkeiron (Designing self-organizing mechanical systems)" published in 2009 by Ohm-sha, Japan. Translation and publication were supported by Grant-in-Aid for Publication of Scientific Research Result (No. 226006) from the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan.

these items, a robot is viewed as an autonomous distributed system. Taking this viewpoint, what needs to be considered to create robots that possess the capability of self-organization is discussed in detail.

Here is an outline of the chapters: Chapter 1 describes the philosophy of design of self-organizing mechanical systems. The discussion here may seem a little abstract but it contains a simple introduction to the notion of autonomous distributed systems, which forms the basis of the concept of self-organization and self-organizing mechanical systems. Chapter 2 considers some examples of self-organization at various levels of hierarchy in biological systems, which is our source of inspiration when we design self-organizing machines and robots. Chapter 3 presents a history of the research related to self-organizing mechanical systems. Instead of providing a complete history, we present several selected topics suitable for grasping the flow of research in this area. Chapter 4 explains some mathematics and methodology necessary for understanding theoretical background to use self-organization phenomena. Chapter 5 demonstrates the feasibility of building a self-organizing machines by introducing an actual machine that is able to assemble itself and repair itself, which is one of the achievements of our own research. Chapter 6 discusses some examples of self-organizing robots which are known as modular robots, and gives several case studies. The reader will see that a variety of robots are being developed based on many different approaches. Chapter 7 and 8 primarily explain M-TRAN, one of the most advanced self-organizing robots at this time, which can create its own shape and robotic motion. Chapter 9 addresses various issues in the implementation and instrumentation of self-organizing robots, suggesting ideas to solve them. Chapter 10 discusses the future of self-organizing robots, especially molecular-level self-organizing robots.*

It is not required to have advanced knowledge of mathematics to read this book. The knowledge that science-oriented undergraduates has will suffice. The assumed readers of this book are students in the existing robotics discipline, including areas such as mechanics, control, electronics, and computer science, and also researchers who wish to look into the area of robotics, or who are working in other areas and have interest in applications of self-organization phenomena.

This book can be read in different ways: who wish to learn the basic concept should start from Chapter 1. Those interested in the fundamentals of self-organizing mechanical systems and robots but not the philosophical arguments may start from Chapter 5 and then continue onto Chapter 6, and so be able to grasp the overall trends in this area and the current research activities. Those interested in developing actual robots are recommended to read Chapters 7 through 9, while referring to Chapter 4 as needed if the reader encounters unfamiliar mathematics.

Here, we would like to explain the background of this book. The authors were researchers in an institute formerly called the Mechanical Engineering Laboratory (MEL) of the Agency of Industrial Science and Technology of the Ministry of

* Extra materials that compliment this book, such as movies of experiments, are available at a web page. These materials can be accessed through http://extras.springer.com/ and by searching with this book's ISBN (please make sure you enter the full ISBN number, including hyphens).

International Trade and Industry, Japan. (Kurokawa is currently affiliated with the National Institute of Advanced Industrial Science and Technology, AIST, into which MEL was incorporated, whereas Murata's current affiliation is Tohoku University.) In MEL, there was a research group on fault-tolerance at the beginning of the 1980s. The group members included Kurokawa, Toshio Fukuda (now at Nagoya University), and Shigeru Kokaji, who was substantially the leader of all the research discussed in this book. This group was one of the birthplaces of self-organizing robots in Japan, as evidenced by Fukuda's pioneering self-organizing robot CEBOT in later years. When Murata joined MEL in 1987, Kokaji had just completed his innovative distributed machine called Fractal Machine. At that time, Kokaji was engaged in constructing parallel computers and had assembled entirely by himself a parallel computer system consisting of 64 microprocessors. This computer gave Kokaji the idea for the Fractal Machine. This machine was a system thoroughly based on the principle of distributed systems and provided in many ways the model for the research that followed.

In the following years, the Synergetics Research Group was founded with Kokaji as the leader. The group was eventually recognized as one of the official research groups of MEL, and new members Kohji Tomita, Eiichi Yoshida, and Akiya Kamimura joined this group one after another. The authors would like to emphasize that many of the results presented in this book are the achievements of all the members of our group.

The authors received much help from people outside the group, including the late Kazuo Tanie at Metropolitan University of Tokyo, and Toshio Fukuda at Nagoya University, who gave us encouragement and valuable advice from time to time. We thank Kohji Ito at Ritsumeikan University that the authors could meet various researchers including the late Hideo Yuasa at Tokyo University, Kazuo Hosokawa at RIKEN, and Akio Ishiguro at Tohoku University.

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The authors are very grateful to Motoko Takenishi of Ohmsha, Ltd. who helped us to write the Japanese version of this book, and Kazuhiko Ogawa and his colleagues at NBT Corporation for their work of translation. If it had not been for their help, this book would not have been completed.

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Lastly, the authors strongly hope that this book will help students and researchers to understand ways of thinking about self-organizing robots, and that some of the readers will be inspired to create the next generation of these mechanical systems.

July 2011

Satoshi Murata
Haruhisa Kurokawa

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