Preface

This book elaborates on the contact mechanics and new control strategies of a two-fingered robotic hand having a pair of hemispherical soft fingertips on the distal position of each finger. The onset of this research dates back about 6 years; at that time I had matriculated at Ritsumeikan University as a first-year master's student intending to specialize in robotics and its controls. At the first meeting of the laboratory at the time, my supervisor, Prof. Hirai, told us why the traditional control schemes of multifingered robotic hands are extremely complicated, whereas human pinching movements are very simple tasks. In that meeting, he immediately demonstrated the precise control of a randomly placed object that is grasped by two finger-like LEGO blocks. We by necessity expected the soft fingertips on the toy to have a simple but important unknown mechanics that directly affected the stable and dexterous manipulation of the object.

This book starts from similar observations about the dynamic behavior of an object using a pair of soft-fingered robotic hands, implying that the formulation of a new mathematical model of soft fingertips is needed to sufficiently describe the oscillatory convergence of a grasped object, which could be found in experimental observations. In the process of modeling, we have analytically discovered the minimal energy induced by the elastic deformation of a fingertip. The change of the elastic energy during manipulation is consistently and constantly exerted to stable grasping and dexterous manipulation all the time, based on which new control methods for two-fingered pinching motions are proposed. In particular, in the latter half of the book, we focus on the design concept of the control method and its performance within soft-fingered manipulation and demonstrate in experiments that the robotic hand can be modeled on a straightforward sensor-based control without using the fingertip model.

The index finger is commonly used with the opposable thumb to create a pinching motion in order to pick up small or thin objects such as needles, pins, or pens. Knitting, crocheting, weaving, general needlework, and other such skills all require considerable effort from the index finger and thumb.

However, none of the conventional robotic hands have attained a high level of dexterity in the performance of given tasks. Considering that reason, it is completely natural to consider that the functional roles of each finger are probably distinct from each other during skilled tasks because the individual physical parameter and musculoskeletal structure of the index finger and thumb are inherently different each other. Based on this point of view, this book reveals that the control loops of both fingers can be completely separated to that of each finger and the objective of each finger movement for control can be determined independently for, say the index finger and the thumb.

We believe that this proposed control scheme for a soft-fingered hand can be implemented in other robotic systems within which one or more other closed-link structures or redundant mechanisms exist. Thus, we expect this book to be given a close and careful reading by researchers who specialize in the field of robotics and who are interested in multivariable feedback control associated with the anthropomorphic robotic hand.

This monograph is based mainly on my doctoral thesis; therefore, I would like to sincerely thank my principal adviser, Prof. Shinichi Hirai. Through 5 years of master's and doctoral courses at Ritsumeikan University, he immediately suggested a cutting-edge topic in completely unexplored territory. He consistently provided me with stimulating discussion about our topic wherever and whenever I desired. As a result, many papers had fortunately been accepted for IEEE conferences and journals.

Finally, I would like to thank my family, who encourages me every day and understands what is involved in writing a book.

Okayama, Japan, October 2008 *Takahiro Inoue*

This book focuses on grasping and manipulation performed by soft fingertips. Most of the chapters are based on the Ph.D. thesis of Dr. Inoue, the coauthor of this book. He joined my laboratory in 2002 as a graduate student. I have been interested in human dexterity in object manipulation, and at that time, I often asked myself why humans can exhibit dexterity in object manipulation despite the delay in the human brain-nerve system. Signal transmission in biological systems is slower than that in computers but current robotics cannot realize human dexterous manipulation. Furthermore, the key to human dexterity has not yet been revealed. At that time, Professor Cutkosky's group and Professor Kao's group had been investigating modeling and mechanics of soft fingertips. Professor Arimoto and his colleagues had been investigating soft-fingered grasping and manipulation extensively with mathematical formulation. Inspired by these researches, Dr. Inoue and I discussed the human grasping and manipulation and stuck upon the idea that human soft fingertips might contribute to dexterity. Dr. Inoue then began to analyze the mechanics of soft fingertips in contact and developed the *parallel-distributed model*, which is the main concept of this book. From 2002 to 2005, he studied extensively the mechanics and control of manipulation by soft fingertips. This was a very fruitful period. He was nominated two successive years as a finalist for the Best Manipulation Paper Award at the IEEE International Conference on Robotics and Automation, 2005 and 2006. In addition, he received the IEEE Kansai Section Student Paper Award in 2006.

We believe that human anatomy contributes to the outstanding human ability to manipulate objects. Our parallel-distributed model reflects the human structure of a soft fingertip and a hard fingernail. Manipulation has been one main topic in robotics research. Many excellent studies have contributed to the area of manipulation in robotics, and I hope that our research will be a valuable contribution.

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Kusatsu, October 2008 *Shinichi Hirai*

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