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Weiliang Xu and John E. Bronlund

Mastication Robots

Biological Inspiration to Implementation



Springer

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Preface

The biological systems we see around us as birds, trees and animals have evolved over millennia. They are complex systems adapted for a multitude of functions including flight, running, reproduction, and digestion. There has been an increasing awareness of these systems by engineers who are now looking to biology as inspiration for design. Mechanical and robotic designs have been developed based on the biomechanics of humans and animals. Similarly computer algorithms, artificial intelligence and control systems have been developed from genetic or neurological principles.

In the study of food science, there has been an increasing trend for engineers and technologists to look further and further down the food product life cycle. In the past the focus has been on food ‘from farm-gate to the plate’. In recent times research has looked past the plate to study what happens to the food in the mouth, during swallowing and throughout the digestion process. Food structures are now being designed from an understanding how the food properties interact with the physiological processes occurring in the mouth and the gut. In this way foods aimed at prevention of diet related disorders can be developed.

In this book we look to merge these two perspectives by developing robots to simulate human mastication. The development of these robots can be applied to physical simulation of human chewing and provide insights into the relationships between food structure and perceived texture during mastication. By developing chewing robots, mechanical design, artificial intelligence and control strategies might be developed for use in other completely unrelated applications.

The robotic simulation of the human mastication system offers a chance to study the biomechanics and control of a complex system. The human mandible is compact and yet it can apply large forces. It can adapt to effectively breakdown disparate materials ranging from fibrous structures like bran to hard brittle foods such as nuts or tough sticky materials like toffee. The jaws trajectory can be controlled to achieve rapid movement without biting the surrounding oral structures such as the cheeks or tongue. Biting is abruptly stopped if even a small unexpected hard object (such as a fragment from an olive pit) is detected between the occlusal surfaces of the teeth. The jaw muscles are strong enough to enable Malaysian strongman “King Tooth” to pull a seven coach train over 4 metres with his teeth and yet we control this force well enough to move a marshmallow with our teeth and barely leave a mark. Understanding how nature achieves this amazingly

broad functionality can potentially lead to a next generation of mechatronic devices or methodologies for their control.

The use of robotic systems to simulate chewing of foods by humans offers tremendous advantages over existing food texture characterisation methods. A robotic jaw can be fully instrumented to allow real time measurement of the magnitude and direction of the forces applied to the food. The true trajectory used to fracture foods can be studied in order to understand if or how we choose optimal strategies to convert the food into a swallow safe bolus in the mouth. From this understanding it may be possible to design food structures that can evade breakdown during chewing and therefore alter the stomach emptying rate or the rate of nutrient release during digestion. Alternatively foods could be structured in order to provide the flavours and tastes we desire in the food at lower concentrations in the food. After all we can't sense flavours that are released from foods after they are swallowed.

Our work on chewing robots began with an impromptu visit in 2002 to the Dentistry School at Université d'Auvergne, Clermont Ferrand, France. There we visited Prof Alain Woda and Dr Marie- Agnès Peyron who were engaged in characterising how food texture affected the way in which it was chewed by human subjects. From this initial meeting the intriguing idea of mechanically reproducing human trajectories to provide textural information of foods was sparked. From this point we formed the unusual combination of food engineering and robotics researchers working together in collaboration to design chewing robots.

To develop biologically inspired masticatory robots we have needed to carry out research in a broad multidisciplinary team. Over the years we have collaborated with food scientists, physiologists, dentists, biomechanics engineers, mechatronics engineers and particle technologists. Without this combination of different perspectives, development of useful systems would be much more difficult.

Much of the hands on work has been done by postgraduates at Massey University. Short term projects have been completed by Ben Daumas, Stefan Seitz, Mark Greenbrook, Aimerly Charbonneau, Gabriel Feraudet, Luc Getto, Sébastien Martin, Thomas Surrel, Thibaud Roquier, Adrien Lauranceau-Moineau, Pierre-Henri Bouhet, Pierre Cambonie, Cyril Nicolotto, Vincent Parinet, and Lars Kuhnert. Masters and PhD students Sebastian Pap, Darren Lewis, Charles Chen, Otmar Nitsche, Jonathan Torrance, Richard Sun and Gauss Li have all worked on varying aspects of robot development and control. PhD students Christine Flynn, Scott Hutchings, Hongyan Yao and Jean Ne Cheong have also contributed through development of the knowledge of human chewing behaviour and its relationship to texture. Many 4th year undergraduates at Albany campus were also involved in simulating our robots for their kinematics and dynamics.

We would like to acknowledge the significant inputs of our collaborators at Massey University. We specifically thank Dr Loulin Huang and Dr Johan Potgieter for joint supervision of robotics focused postgraduate students and Prof Jim Jones, Prof Roger Lentle and Dr John Grigor for joint supervision of human food mastication focussed research projects. Dr Dong (Walter) Xie also contributed to this work with respect to developing knowledge systems for food mastication.

Special thanks go to Dr Kylie Foster who has had a very active role in human chewing behaviour based research.

We have also had guidance and collaboration from the wider research community. The advice and encouragement from the members of the Biomouth research group (<http://www.biomouth.org>) has been appreciated, particularly the valuable contributions on occlusion and dental materials from Prof Jules Kieser and his associates at the School of Dentistry, University of Otago, New Zealand. Robotic design has been assisted by the insights on jaw biomechanics provided by Prof Andrew Pullan from the Bioengineering Institute, University of Auckland, New Zealand, and Dr Oliver Röhrle from the Institute of Applied Mechanics, University of Stuttgart, Germany.

We have enjoyed a significant and ongoing collaboration with Marco Morgenstern and his colleagues from The New Zealand Institute of Plant and Food Research. This research has been very productive in terms of both robotic design and in understanding food texture. A similar collaboration has been established with the members of the Riddet Institute based at Massey University, New Zealand, linking understanding of foods in the mouth to the understanding of foods in the gut.

Through these collaborations we have benefited from good research funding. In particular we would like to acknowledge the funding received from Massey University and the New Zealand Foundation for Research, Science and Technology through our collaborations with Plant and Food Research, The Bioengineering Institute, and the Riddet Institute.

We also appreciate the willingness of researchers from around the world to engage in discussions and the sharing of ideas. The interactions with Dr Marie-Agnès Peyron, Prof Alain Woda, Dr Martin Wickham, Prof Jose Aguilera, Assoc/Prof Anuchita Moongngarm, Prof Paul Singh, Prof Osvaldo Campanella and Dr Yacine Hemar have been especially useful.

Much of the content of this book has been produced through the collaborations listed above. Specific contributions are acknowledged in each chapter. Thanks to Julie Rayner for help in editing the manuscript.

In Chapter 1, mastication in humans is reviewed together with details of mastication robots reported in the literature. Chapter 2 outlines robotic models of the mastication system as a basis for robot design. Chapters 3 and 4 outline alternative designs for robots of various parallel configurations, demonstrating the sequence of steps made in the design process. A simpler chewing robot based on a 4-bar linkage mechanism is presented in Chapter 5. This device was developed for use by food engineers interested in understanding the dynamics of food texture.

The later chapters in the book are aimed at application of the chewing robots to provide understanding of real food systems. In Chapter 6, the measurement of human chewing trajectories is discussed together with how they can be adapted to make them suitable for implementation on the robotic systems. Chapter 7 details experimental work carried out to validate the force measurements made using the 6RSS chewing robot for a number of simplified and real jaw trajectories on a variety of food products. In Chapter 8 attention is turned to how the results generated from the robotic devices discussed in this book and in the literature can be

interpreted to understand food texture. The key functionality required for this purpose is reviewed and the current capability of each device is evaluated.

Chapter 9 outlines novel approaches to high level control of mastication robots using neural control systems inspired from the way the human chewing process is controlled using the central nervous system. Finally Chapter 10 outlines the application of knowledge frameworks as a tool to consolidate the data on food mastication collected from experiments on humans and robots. Such systems are required in order to make sense, through methods such as data mining, of the large repository of information available.

This book summarises a large body of research on masticatory robots and its content demonstrates how complex robotic design can be carried out to provide useful tools for the food industry. We expect that the human chewing inspired designs and control strategies developed here can be implemented as novel solutions to other industrial applications. While further development of masticatory robots is still required, accurate reproduction of human chewing is not far away.

Auckland, New Zealand, 2010

Weiliang Xu
John Bronlund

Contents

1	Introduction	1
1.1	Why Mastication Robots	1
1.2	The Masticatory System	3
1.2.1	Jaw and Temporomandibular Joint	3
1.2.2	Muscles of Mastication	5
1.2.3	Teeth	6
1.3	Measurement of Mastication Movement	7
1.3.1	Jaw Movement	8
1.3.2	Chewing Forces	10
1.4	Computational Models of the Masticatory System	12
1.4.1	Dynamics Models	12
1.4.2	Kinematics Model	14
1.5	Mastication Robots	15
1.5.1	Dental Training Robot	15
1.5.2	Jaw Simulator	18
1.5.3	Foods Chewing Robot	19
1.5.4	Other Mastication Robots	23
1.6	Computational Intelligence in Mastication	24
1.7	Discussion	26
1.8	Summary	28
	References	28
2	Robotic Models of the Masticatory System	35
2.1	A Mechanism Model of the Masticatory System	35
2.1.1	Jaw Muscles and Movements	35
2.1.2	Jaw Mechanism Modeling	37
2.2	Kinematics Simulations in SimMechanics	39
2.2.1	Physical Quantities of the Mechanism	40
2.2.2	Actuation Modes	41
2.2.3	Results and Analysis	42
2.3	A Robotic Model of the Masticatory System	45
2.3.1	The Robotic Model	45
2.3.2	Physical Quantities of the Model	46
2.4	Kinematics Simulation in SolidWorks/CosmosMotion	49

2.4.1 Forward Kinematics Simulation	50
2.4.2 Inverse Kinematics Simulation	53
2.5 Summary	57
References	58
3 Mastication Robot of Linear Actuation	59
3.1 A Refined Robotic Model	59
3.2 Motion Design of the Actuation	62
3.3 Force Design of the Actuation	65
3.4 Design of the Actuation System	67
3.4.1 Basic Design Requirements	67
3.4.2 Types of Actuation	68
3.4.3 Actuator Control	71
3.4.4 Physical Design	73
3.5 Design of Mastication Robot	85
3.5.1 Actuator Assembly	86
3.5.2 Actuator Mounting	88
3.6 Summary	88
References	89
4 Mastication Robot of Crank Actuation	91
4.1 The 6RSS Parallel Mechanism	91
4.2 Coordinate Systems and Kinematical Parameters	93
4.3 Inverse Kinematics	95
4.4 Singularity Analysis	97
4.5 Design of the Robot	98
4.5.1 Framework Design	98
4.5.2 Lower and Upper Jaw	100
4.6 Motion Control	102
4.7 Simulation in SolidWorks/CosmosMotion	104
4.8 Simulation in SimMechanics	110
4.9 Initial Chewing Experiments	121
4.9.1 Masticatory Movements	121
4.9.2 Robotic Chewing without Food	121
4.9.3 Robotic Chewing of Simulated Foods	124
4.10 Summary	128
References	128
5 Mastication Robot of a Crank-Slider Linkage	129
5.1 Why a Linkage Mechanism for Mastication	129
5.2 Design Specifications	131
5.3 Basic Linkage Mechanism for an Incisor Trajectory	132
5.4 Six-Bar Linkage Mechanism for Jaw Movement	138
5.4.1 The Six-Bar Linkage	138
5.4.2 Motion Planning	139
5.4.3 Motor Selection	141

5.5	Analysis of the Mechanism.....	142
5.5.1	Trajectory and Force Evaluation.....	142
5.5.2	Stress and Deformation.....	143
5.6	Mechanical Design of the Mechanism.....	145
5.6.1	Limiting the Chewing Force.....	145
5.6.2	The Enclosure.....	145
5.6.3	Teeth Locking.....	147
5.6.4	The Teeth and Food Retention System.....	149
5.7	Measurement of the Chewing Force.....	152
5.8	The Control System.....	153
5.8.1	Computer/Motor Interface.....	153
5.8.2	Hall Effect Sensor.....	154
5.8.3	The Software Functions.....	156
5.8.4	Chewing Trajectory Setting.....	156
5.9	Chewing Experiments.....	158
5.9.1	Operation of the Chewing Robot.....	158
5.9.2	Results and Discussion.....	159
5.10	Summary.....	162
	References.....	162
6	Measurement and Reproduction of Mastication Movement	163
6.1	Mastication Measurement.....	163
6.1.1	The Techniques.....	163
6.1.2	The Measurement.....	164
6.2	Coordinate Systems for the Movement.....	165
6.2.1	The Sensor and Mandible Systems.....	165
6.2.2	The Skull System.....	167
6.3	Reproduction of the Movements.....	169
6.4	GUIs for Analysis of the Movements.....	173
6.5	Summary.....	176
	References.....	177
7	Robotic Chewing Experiments	179
7.1	Introduction.....	179
7.2	Force Measurement.....	181
7.3	Experiments for One-DOF Chewing Trajectory.....	184
7.4	Experiments with Two-DOF Chewing Trajectory.....	189
7.5	Experiments with Six-DOF Chewing Trajectory.....	198
7.6	Summary.....	205
	References.....	206
8	Understanding Food Texture Using Masticatory Robots.....	207
8.1	Introduction.....	207
8.2	Specifying a Mastication Robot for Texture Measurement	209
8.2.1	Tooth Shape.....	211
8.2.2	Teeth Kinematics.....	211

8.2.3	Control Strategy	212
8.2.4	Sample Size and Manipulation	213
8.2.5	Bolus Retention and Losses	214
8.2.6	Moisture and Temperature Control	215
8.3	Masticatory Robots – Current Capability	216
8.3.1	Waseda Jaws Mastication Robot	216
8.3.2	BITE Master II	217
8.3.3	INRA Flavour Release Chewing Simulator	219
8.3.4	Linkage Mechanism Mastication Robot	222
8.3.5	Six-DOF Parallel Chewing Robot	231
8.3.6	Other Oral Simulation Devices	233
8.4	Summary	234
	References	234
9	Neural Control of a Mastication Robot	237
9.1	Why CPG for Control	237
9.2	Matsuoka Oscillator Fundamentals	239
9.3	Tuning of a Matsuoka Oscillator	241
9.3.1	GUI for Simulation of the Oscillator	241
9.3.2	GUI for Influence of the Oscillator Parameters	243
9.3.3	GUI for Adaptation of the Oscillator	244
9.4	Case Study	248
9.4.1	Purpose and Assumptions	248
9.4.2	Modeling of the Masticatory Muscles	249
9.4.3	Simulations	251
9.5	Hardware-in-the-Loop Simulations	256
9.5.1	Simulation Setup	256
9.5.2	Implementation of the Algorithm	259
9.5.3	Experimental Results	263
9.6	Summary	268
	References	269
10	Knowledge System of Human Chewing Behaviours	271
10.1	The Need for Knowledge Systems	271
10.2	Object-Oriented Knowledge Representation	273
10.2.1	Object-Oriented Model Describing Jaw Physiology	273
10.2.2	Object-Oriented Model for the Chewing Process	274
10.3	Knowledge Discovery	276
10.3.1	Data Mining for Association Rules	276
10.3.2	Object-Oriented Model Describing Inter-property Association	277
10.3.3	Object-Oriented Knowledge Representation	277
10.3.4	Data Pre-processing	279
10.3.5	Implementation	279
10.4	Case Study	280
10.4.1	Attributes of the Chewing Properties	280

10.4.2 Pre-processing of Raw Data for Data Mining.....281

10.4.3 Data Mining Results and Their Interpretation282

10.5 Summary284

References284

Appendix286

Index289