Weiliang Xu and John E. Bronlund

Mastication Robots

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Mastication Robots

Biological Inspiration to Implementation

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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, Aimery 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