# 2 Abstracts

## New Concepts for Distributed Actuators and Their Control

**Welf-Guntram Drossel, Holger Schlegel, Michael Walther, Philipp Zimmermann, André Bucht**

Fraunhofer Institute for Machine Tools and Forming Technology IWU, Chemnitz

**Abstract** Recently, decreasing costs for robots and control components have led to a broader acceptance of different kinds of robots. Hence, various fields of application start to flourish. As this is especially true for the field of service robotics it is typically implying an increasing physical human-machine-interaction. In this case a soft appearance yields major benefits, as it prevents injuries corresponding to an inherent safety of the system and, in theory, enables the robot to obtain virtually unlimited degrees of freedom. In this chapter the possibilities of the use of shape memory alloys for distributed actuators will be discussed by reference to application examples and implications for the control of such systems will be pointed out in detail.

## Artificial Muscles, Made of Dielectric Elastomer Actuators - A Promising Solution for Inherently Compliant Future Robots

**In Seong Yoo, Sebastian Reitelshöfer, Maximilian Landgraf, Jörg Franke**

Friedrich-Alexander-Universität Erlangen-Nürnberg

**Abstract** The cutting-edge robotic technology can deal with a lot of complex tasks. However, one of the most challenging technological obstacles in robotics is the development of soft actuators. Remaining challenges in the field of drive technology can be overcome with innovative actuator concepts, for example dielectric elastomer actuators (DEAs). DEAs show numerous advantages in comparison to prevailing robotic actuators that are based on geared servomotors: They are form-flexible, inherently compliant, can store and recuperate kinetic energy, feature high power-to-weight ratio and high energy density that is comparable to human skeletal muscles, and finally can be designed to perform natural motion patterns

A. Verl et al. (eds.), *Soft Robotics,* DOI 10.1007/978-3-662-44506-8_2,

other than rotation. In this article, after a review on disadvantages of state-of-art robotic drives, which are stimulus for a research on the promising drive solution, benefits of DEAs will be presented with regard to the possibility of applications in soft robotics. Finally, the article will conclude with a brief report on the ongoing research effort at the Institute for Factory Automation and Production Systems (FAPS) with two major foci – the development of an automated manufacturing process for stacked DEAs and a lightweight control hardware.

## Musculoskeletal Robots and Wearable Devices on the Basis of Cable-driven Actuators

**Martin Haegele, Christophe Maufroy, Werner Kraus, Maik Siee, Jannis Breuninger**

Fraunhofer Institute of Manufacturing Engineering and Automation IPA, Stuttgart

**Abstract** Cable-driven actuators are a promising alternative for future kinematic designs, particularly when the combination of lightweight, high strength, compact designs and dynamic motions are required. Powered exoskeletons or wearable robots are typical candidates of these novel actuators as has been demonstrated by previous research. This chapter focusses on current work in cable-driven actuators, introduces the Myorobotics toolkit for supporting the engineer to build up prototypes from cable-actuates modules and gives an outlook to using cable-driven actuation for advanced wearable robots.

## Capacitive Tactile Proximity Sensing: From Signal Processing to Applications in Manipulation and Safe Human-Robot Interaction

**Stefan Escaida Navarro, Björn Hein, and Heinz Wörn**

Karlsruhe Institute of Technology (KIT)

**Abstract** Recently we have shown developments on capacitive tactile proximity sensors (CTPS) and their applications. In this work we give an overview of these developments and put them into a more general perspective, emphasizing what the common grounds are for the different applications, i.e., preshaping and grasping, haptic exploration as well as collision avoidance and safe human-robot interaction. We discuss issues related to signal processing and the design of a smart skin for the robot arm and its end-effector. On a higher level we discuss the concept of proximity servoing and its use for the above mentioned applications.

## Perception of Deformable Objects and Compliant Manipulation for Service Robots

**Jörg Stückler and Sven Behnke**

University of Bonn

**Abstract** We identified softness in robot control as well as robot perception as key enabling technologies for future service robots. Compliance in motion control compensates for small errors in model acquisition and estimation and enables safe physical interaction with humans. The perception of shape similarities and deformations allows a robot to adapt its skills to the object at hand, given a description of the skill that generalizes between different objects. In this chapter, we present our approaches to compliant control and object manipulation skill transfer for service robots. We report on evaluation results and public demonstrations of our approaches.

## Soft Robot Control with a Behaviour-Based Architecture

**Christopher Armbrust, Lisa Kiekbusch, Thorsten Ropertz, Karsten Berns**

University of Kaiserslautern

**Abstract** In this chapter, we explain how behaviour-based approaches can be used to control soft robots. Soft robotics is a strongly growing field generating innovative concepts and novel systems. The term “soft” can refer to the basic structure, the actuators, or the sensors of these systems. The soft aspect results in a number of challenges that can only be solved with new modelling, control, and analysis methods whose novelty matches those of the hardware. We will present prior achievements in the area of behaviour-based systems and suggest their appli-

cation in soft robots with the aim to increase the fault tolerance while improving the reaction to unexpected disturbances.

## Optimal Exploitation of Soft-Robot Dynamics

**Sami Haddadin**

Leibniz University Hannover

**Abstract** Inspired by the elasticity contained in human muscles, elastic soft robots are designed with the aim of imitating motions as observed in humans or animals. Especially reaching peak velocities using stored energy in the springs is a task of significant interest. In this chapter, general results on maximizing a soft-robot's end-point velocity by using elastic joint energy are presented and discussed.

## Simulation Technology for Soft Robotics Applications

**Jürgen Roßmann, Michael Schluse, Malte Rast, Eric Guiffo Kaigom, Torben Cichon**

RWTH Aachen University

**Abstract** Soft robots are implied to be inherently safe, and thus "compatible", not only with human coworkers in a production environment, but also with the "family around the house". Such soft robots today still hold numerous new challenges for their design and control, for their commanding and supervision approaches as well as for human-robot interaction concepts. The research field of eRobotics is currently underway to provide a modern basis for efficient soft robotic developments. The objective is to effectively use electronic media - hence the "e" at the beginning of the term - to achieve the best possible advance in the research field. A key feature of eRobotics is its capability to join multiple process simulation components under one "software roof" to build "Virtual Testbeds", i.e. to alleviate the dependancy on physical prototypes and to provide a comprehensive tool chain support for the analysis, development, testing, optimization, deployment and commanding of soft robots.

## Concepts of Softness for Legged Locomotion and Their Assessment

**Andre Seyfarth, Katayon Radkhah, Oskar von Stryk**

Technische Universität Darmstadt

**Abstract** In human and animal locomotion, compliant structures play an essential role in the body and actuator design. Recently, researchers have started to exploit these compliant mechanisms in robotic systems with the goal to achieve the yet superior motions and performances of the biological counterpart. For instance, compliant actuators such as series elastic actuators (SEA) can help to improve the energy efficiency and the required peak power in powered prostheses and exoskeletons. However, muscle function is also associated with damping-like characteristics complementing the elastic function of the tendons operating in series to the muscle fibers. Carefully designed conceptual as well as detailed motion dynamics models are key to understanding the purposes of softness, i.e. elasticity and damping, in human and animal locomotion and to transfer these insights to the design and control of novel legged robots. Results for the design of compliant legged systems based on a series of conceptual biomechanical models are summarized. We discuss how these models compare to experimental observations of human locomotion and how these models could be used to guide the design of legged robots and also how to systematically evaluate and compare natural and robotic legged motions.

## Mechanics and Thermodynamics of Biological Muscle - A Simple Model Approach

**Syn Schmitt and Daniel Haeufle**

University of Stuttgart

**Abstract** Macroscopic muscle models allow for a detailed analysis of the mechanic and thermodynamic function of biological muscles. Here we summarize results from various simulation studies which emphasize the extraordinary design features of biological muscles. Discussed are the benefits resulting from (2) wobbling masses and the muscles soft-tissue inertia effects, (2) biological damping,

(3) internal mass distribution, (4) stabilising properties of active muscles in upright stance and periodic hopping, (5) reduced control effort due to these stabilising effects. We present approaches to systematically transfer these results to technical actuators and exploit these properties in the next generation of functional artificial muscles.

## Nanostructured Materials for Soft Robotics – Sensors and Actuators

**Raphael Addinall[1], Thomas Ackermann[1, 2] and Ivica Kolaric[1]**

[1] Fraunhofer Institute for Manufacturing Engineering and Automation IPA, Stuttgart

[2] Graduate School of Excellence advanced Manufacturing Engineering (GSaME), University of Stuttgart

**Abstract** The advances in nanotechnology during the past two decades have led to several breakthroughs in material sciences. Ongoing and future tasks are related to the transfer of the unique properties of nanostructured materials to the macroscopic behaviour of composite structures and the system integration of novel materials for improved mechanical, electronic and optical devices. Nanostructured carbons, especially carbon nanotubes, are promising candidates as novel material for future applications in several fields. One of the big aims is the utilisation of the unique intrinsic mechanical and electronic properties of carbon nanotubes for sensing and actuation devices. The combination of excellent electrical conductivity and mechanical deformation makes carbon nanotubes ideal for applications in sensors and actuators and opens new possibilities in construction design of next generation robotic systems, which can be built with soft, bendable and stretchable materials. This chapter gives a brief overview on the properties of carbon nanotubes and their potential for actuators and sensors in soft robotics.

## Fibrous Materials and Textiles for Soft Robotics

**M. Milwich[1, 2], S.K. Selvarayan[1], G.T. Gresser[1]**

[1]Institute of Textile Technology & Process Engineering Denkendorf, [2]Hochschule Reutlingen

**Abstract** Soft, mechanically compliant robots are developed to safely interact with a "human environment". The use of textiles and fibrous (composite-) materials for the fabrication of robots opens up new possibilities for "Softness/Compliance" and safety in human-robot interaction. Besides external motion monitoring systems, textiles allow on-board monitoring and early prediction, or detection, of robot-human contact. The use of soft fibers and textiles for robot skins can increase the acceptance of robots in human surroundings. Novel topology optimization tools, materials, processing technologies and biomimetic engineering allow developing ultra-light-weight, multifunctional, and adaptive structures.

## Opportunities and Challenges for the Design of Inherently Safe Robots

**Annika Raatz, Sebastian Blankemeyer, Gundula Runge, Christopher Bruns, Gunnar Borchert**

Leibniz University Hannover

**Abstract** An approach for solving the challenges that arise from the increased complexity of modern assembly tasks is believed to be human robot co-operation. In these hybrid workplaces humans and robots do not only work on the same task or interact during certain assembly steps, but also have overlapping workspaces. Therefore, 'safe robots' should be developed that do not harm workers in case of a collision. In this chapter, an overview of methods for designing a hardware based soft robot that is inherently safe in human-machine interaction is given. Recent projects show that robots could be soft enough for interaction but they are not able to resist forces that occur in the assembly process. Current solutions show that the designer of such robots must face a trade-off between softness and dexterity on the one hand and rigidity and load carrying capabilities on the other hand. A promising approach is to integrate variable stiffness elements in the robotic system. The chapter classifies two main design rules to achieve stiffness variability, the tuning of material properties and geometric parameters. Existing solutions are described and four concepts are presented to show how different mechanisms and materials could be combined to design safe assembly robots with a variable stiffness structure.

## Aspects of Human Engineering – Bio-optimized Design of Wearable Machines

**C. Hochberg, O. Schwarz, U. Schneider**

Fraunhofer Institute for Manufacturing Engineering and Automation IPA, Stuttgart

**Abstract** This chapter outlines important factors for the design process of wearable robots. First, the challenges are discussed and possible user groups are detailed and categories of devices given. Then, major differences of classical design methods from the field of robotics are illustrated. This is due to linking between the machine and the user and challenges of user intention detection. Finally, some design approaches, guidelines and best practices for the development of wearable devices are discussed.

## 3D Printed Objects and Components Enabling Next Generation of True Soft Robotics

**Andreas Fischer, Steve Rommel, Alexander Verl**

Fraunhofer Institute for Manufacturing Engineering and Automation IPA, Stuttgart

**Abstract** Soft robotics in the content of true softness, with regards to components, parts, or the complete robot, are the next step in the development of tools for humans, especially when used in close proximity. Considering the fact that robots are a multilevel extension of the human body, and that their main purpose should be to help humans perform tasks, then focusing on the development of soft-materials, and product design options allowing for flexibility and softness by design is necessary, for the next development level of the tool “robot”. Using additive manufacturing in combination with new materials, design methods, and biomimicry / biomimetics is a key in that development, but also very challenging due to the multi-level complexity. An understanding of the real world tasks required to be performed, and abstracting this information into new applications and robotic designs in the combination mentioned above, is shown in the chapter, functioning as a basis and overview of the state-of-the-art.

## Soft Hands for Reliable Grasping Strategies

**Raphael Deimel and Oliver Brock**

University of Technology Berlin

**Abstract** Recent insights into human grasping show that humans exploit constraints to reduce uncertainty and reject disturbances during grasping. We propose to transfer this principle to robots and build robust and reliable grasping strategies from interactions with environmental constraints. To make implementation easy, hand hardware has to provide compliance, low inertia, low reaction delays and robustness to collision. Pneumatic continuum actuators such as PneuFlex actuators provide these properties. Additionally they are easy to customize and cheap to manufacture. We present an anthropomorphic hand built with PneuFlex actuators and demonstrate the ease of implementing a robust multi-stage grasping strategy relying on environmental constraints.

## Task-specific Design of Tubular Continuum Robots for Surgical Applications

**Jessica Burgner-Kahrs**

Leibniz University Hannover

**Abstract** Tubular continuum robots are the smallest among continuum robots. They are composed of multiple, precurved, superelastic tubes. The design space for tubular continuum robots is infinite: each one of the component tubes can be individually parameterized in terms of its length, segmental curvatures, diameter, and material properties. Ad-hoc selection of those parameters is extremely challenging, since the elastic coupling of concentrically arranged and actuated tubes is hard to predict with common sense, especially under the presence of workspace constraints. In this chapter, an overview of the design process is given and the current state of the art in task-specific design of tubular continuum robots is reviewed.

## Soft Robotics with Variable Stiffness Actuators: Tough Robots for Soft Human Robot Interaction

**Sebastian Wolf, Thomas Bahls, Maxime Chalon, Werner Friedl, Markus Grebenstein, Hannes Höppner, Markus Kühne*, Dominic Lakatos, Nico Mansfeld, Mehmet Can Özparpucu, Florian Petit, Jens Reinecke, Roman Weitschat and Alin Albu-Schäffer**

German Aerospace Center (DLR)

**Abstract** Robots that are not only robust, dynamic, and gentle in the human robot interaction, but are also able to perform precise and repeatable movements, need accurate dynamics modeling and a high-performance closed-loop control. As a technological basis we propose robots with intrinsically compliant joints, a stiff link structure, and a soft shell. The flexible joints are driven by Variable Stiffness Actuators (VSA) with a mechanical spring coupling between the motor and the actuator output and the ability to change the mechanical stiffness of the spring coupling. Several model based and model free control approaches have been developed for this technology, e.g. Cartesian stiffness control, optimal control, reactions, reflexes, and cyclic motion control.

## Soft Robotics Research, Challenges, and Innovation Potential, Through Showcases

**Cecilia Laschi**

The BioRobotics Institute, Scuola Superiore Sant'Anna, Pisa

**Abstract** Soft robotics, intended as the use of soft materials in robotics, is a young yet promising and growing research field. The need for soft robots emerged in robotics, for facing unstructured environments, and in artificial intelligence, too, for implementing the embodied intelligence, or morphological computation, paradigm, which attributes a stronger role to the bodyware and its interaction with the environment. Using soft materials for building robots poses new technological challenges: the technologies for actuating soft materials, for embedding sensors into soft robot parts, for controlling soft robots are among the main ones. Though still in its early stages of development, soft robotics is finding its way in a variety of applications, where safe contact is a main issue, in the biomedical field, as well

http://www.springer.com/978-3-662-44505-1

Soft Robotics
Transferring Theory to Application
Verl, A.; Albu-Schäffer, A.; Brock, O.; Raatz, A. (Eds.)
2015, VIII, 291 p. 100 illus., Hardcover
ISBN: 978-3-662-44505-1