An Overview of Modeling and Control Techniques for Soft Robots

Marilu Ortiz and Sang-Eun Song
Mechanical & Aerospace Engineering
University of Central Florida

Contents

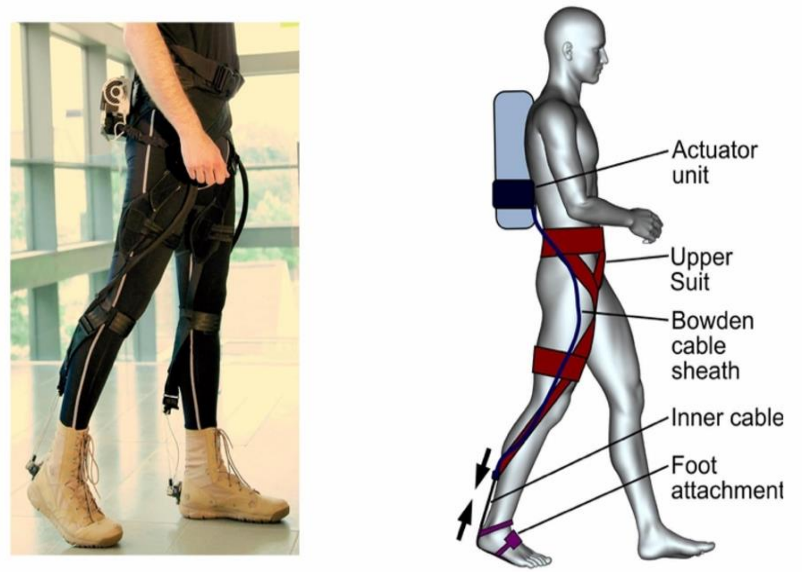
- Introduction to Soft Robotics
- Medical Applications
  - Assistive Devices
  - Minimally Invasive Devices
  - Implantable Devices
- Modeling and Control Techniques
  - Importance
  - Challenges
  - Recent Work

Soft Robotics

- Multidisciplinary field
- Objectives
  - Develop light, soft, flexible and compliant devices
  - Highly adaptable to environment
  - Similar to living organisms
- Recent work and future technologies
  - Adoption of flexible self-powered systems [14]
  - Miniaturization
  - Smart fabrics
  - Autonomous performance
  - Low maintenance, independent operation, and sustainability for implantable biomedical devices [14]
  - Visionary: Self-repairing, growing, and self-replicating robots [15]

Medical Applications
Assistive Devices: Soft Robotic Exosuit

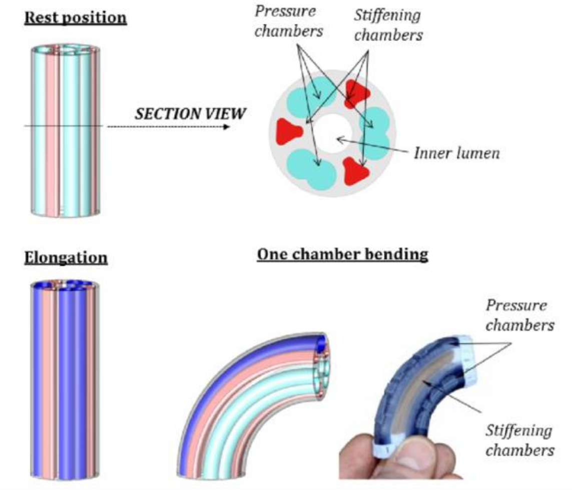
- Clinical application
  - Rehabilitation and/or enhance of movement
- How it works
  - Translate small amount of force by mechanical actuators in the suit to create effective motions
- Soft robot advantages
  - Light weight
  - Does not conflict with human natural movements



Harvard University [12]

Medical Applications
Minimally Invasive Devices: STIFF-FLOP

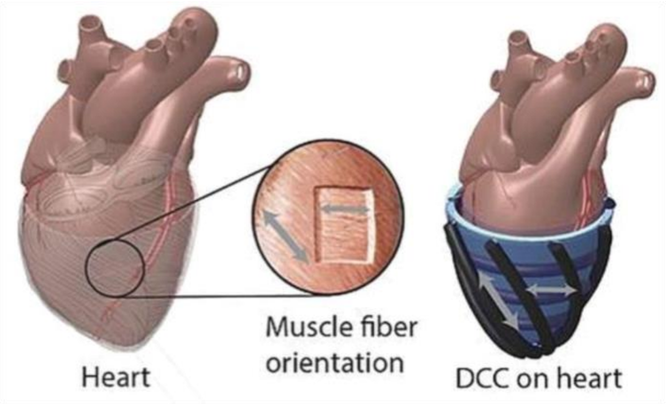
- Clinical application
  - Minimally Invasive Surgical applications
- How it works
  - Modular structure composed of soft and flexible materials
  - Capable to modulate stiffness by using the concept of granular jamming
- Soft robot advantages
  - Can squeeze (reduced its diameter by 40%)
  - Can bend and elongate
  - Produce forces up to 47 N

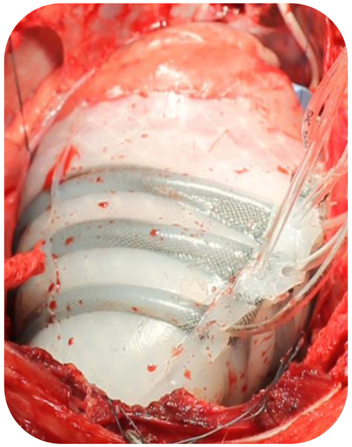


STIFF-FLOP [3]

Medical Applications
Implantable Devices: Heart Sleeve

- Clinical application
  - Provide ventricular assistance
- How it works?
  - Mimic heart contraction and relaxation
  - Use compressed air to power artificial silicone muscles
- Soft robot advantages
  - No blood contact
  - Can be customized
  - Can act as a bridge to transplant for patients with heart failure





Harvard University [11]

Modeling and Control Techniques

- Importance
  - Optimum control design
  - Reliable and repeatable device performance
  - Device safety and efficacy
  - Prepare devices for commercialization

Challenges in Modeling Soft Structures

- Non linear behavior
- System parameters not readily available
- Redundant actuation
- Motion depends on deformation
- Infinite degrees of freedom
- Interactions with environment

Recent Work

- Numerical Model – Constitutive Laws [10][6][1]
  - Experimental Work
  - Finite Element Methods
  - Model order reduction optimization
- Interactive Modeling [1]
  - FEM computes robot's non- linear deformation in real time
  - A reduced compliance matrix is obtained between actuators and end effectors.
  - Iterative algorithm uses compliance matrix to find the actuators contribution needed to deform the structure as desired
- Non – parametric online modeling [4]
  - Generic control framework
  - Use a live motion tracking system
  - State variables are tracked at all times
  - Control system computes control commands based on real time information

UCF

Future Work

- Model order reduction optimization techniques
- Inverse dynamic problem optimization techniques
- Model free approaches
- Anticipate and manage interactions with environment

Questions

References

1. C. Duriez, "Control of Elastic Soft Robots based on Real-Time Finite Element Method," 2013 IEEE International Conference on Robotics and Automation, Karlsruhe, 2013, pp. 3782-3787. doi: 10.1107/ICRA.2013.6631138.
2. C. Duriez *et al*., "Framework for online simulation of soft robots with optimization-based inverse model," *2016 IEEE International Conference on Simulation, Modeling, and Programming for Autonomous Robots (SIMPAR)*, San Francisco, CA, 2016, pp. 111-118. doi: 10.1107/SIMPAR.2016.7862384.
3. Cianchetti, M., et al. (2014). "Soft Robotics Technologies to Address Shortcomings in Today's Minimally Invasive Surgery: The STIFF-FLOP Approach." Soft Robotics 1 (2): 122-131.
4. Lee, K.-H., et al. (2017). "Nonparametric Online Learning Control for Soft Continuum Robot: An Enabling Technique for Effective Endoscopic Navigation." Soft Robotics 4(4): 324-337.
5. M. Ortiz, “Soft Robotics Recent Developments in Minimally Invasive Surgery and Implantable Medical Devices”, US-Korea Conference on Science, Technology and Entrepreneurship (UKC 2017), Washington DC, 2017, pp. 175. ISBN 778-0-7767473-7-4.
6. M. Thieffry, et al. Dynamic Control of Soft Robots. IFAC World Congress, Jul 2017, Toulouse, France.
7. Reddy, J. (2013). An Introduction to Continuum Mechanics. (2nd ed.) Cambridge: Cambridge University Press. doi:10.1017/CBO9781139178952.001
8. Rus, D. et al. (2015). Design, fabrication and control of soft robots. Nature 521, no. 7553.
9. Sarthak Misra, et al. Modeling of Tool-Tissue Interactions for Computer-Based Surgical Simulation: A Literature Review. Presence: Teleoperators and Virtual Environments 2008 17:5, 463-471.
10. Saunders, F. (2010). Modeling locomotion of a soft-bodied arthropod using inverse dynamics. Bioinspiration & biomimetics, 6(1), 016001.
11. Roche, Ellen T., et al. “Soft Robotic Sleeve Supports Heart Function.” Science Translational Medicine, American Association for the Advancement of Science, 18 Jan. 2017.
12. Asbeck, Alan T., et al. “A Biologically Inspired Soft Exosuit for Walking Assistance.” The International Journal of Robotics Research, vol. 34, no. 6, 2015, pp. 744–762., doi:10.1177/0278364914562476.
13. V. Bartenbach, et al. “A lower limb exoskeleton research platform to investigate human-robot interaction,” in IEEE International Conference on Rehabilitation Robotics, pp. 600–605, Singapore, 2015
14. Geon-Tae Hwang, et al. Self-Powered Cardiac Pacemaker Enabled by Flexible Single Crystalline PMN-PT Piezoelectric Energy Harvester. Advanced Materials, 2014; DOI:10.1002/adma.201400562.
15. IEEE Robotics & Automation Society, http://www.ieee-ras.org/soft-robotics.

UCF