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Workshop / Tutorial on Continuum Robots for Surgery: Modeling, Control and Applications

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Abstract

The past decade has witnessed accelerated growth of medical robotics and computer-assisted medical technologies that rely on dexterous tools to enable new surgical procedures. Lately, there has been a growing trend of adopting continuum robots as a design solution for dexterous intervention. These robots present modeling and control challenges beyond the standard modeling and control paradigms for rigid-link serial robots. This half-day workshop that is targeted towards graduate students interested in pursuing research in the area of continuum robot modeling, control and applications. The workshop will cover surgical applications, kinematic and static modeling, sensing, and control of these robots.

Presenter Biographical Sketch

Nabil Simaan received his Ph.D. in mechanical engineering from the Technion - Israel Institute of Technology, in 2002. In 2003, he was a Postdoctoral Research Scientist at Johns Hopkins University National Science Foundation (NSF) Engineering Research Center for Computer-Integrated Surgical Systems and Technology (ERC-CISST), where he focused on minimally invasive robotic assistance in confined spaces. In 2005, he joined Columbia University, New York, NY, as an Assistant Professor of mechanical engineering and the Director of the Advanced Robotics and Mechanisms Applications (ARMA) Laboratory. In 2009 he received the NSF Career award for young investigators to design new algorithms and robots for safe interaction with the anatomy. In 2010 he joined Vanderbilt University. He is a Senior Member of the IEEE. He served as an Editor for *IEEE International Conference on Robotics and Automation (ICRA)* (2013-2015), Associate Editor for *IEEE Transactions on Robotics (TRO)* (2012-2016), Editorial board member of *Robotica*, Area Chair for *Robotics Science and Systems* (2014, 2015) and Corresponding Co-Chair for the IEEE Technical Committee on Surgical Robotics.

Long Wang received his B.S in mechanical engineering from Tsinghua University, Beijing, China, in 2010 and the M.S. degree in mechanical engineering from Columbia University, New York, NY, in 2012. He is currently working toward the Ph.D. degree with the Department of Mechanical Engineering, Vanderbilt University, Nashville, TN. Since 2013 he has been working as a research assistant on a 5-year collaborative NRI Large grant (National Robotic Initiative) - Complementary Situational Awareness for Human-Robot Partnerships. His research interests include modeling and calibration of continuum robots, surgical robotics and force-controlled robot exploration.

Expected Background of Participants

Knowledge of robot kinematics and statics. Basic knowledge of robot force control and compliant motion control and estimation theory would be helpful.

Expected Audience

This workshop/tutorial addresses graduate students, engineers from industry, and faculty interested in continuum robots and their surgical applications. Professionals working in related areas such as medical and surgical devices may find topics covered interesting as well.

Need for the Workshop/Tutorial

For the past decade, medical applications have been a primary driving factor for continuum robot research. Significant efforts have been made in design, modeling, control and sensing of continuum robots. Introduction of modern control and estimation techniques in continuum robots is necessary to improve the motion and sensing capability on various designs. Therefore, the proposed workshop is both timely and relevant and ASME DSCC is an appropriate venue given the focus on the intersection of estimation and control that this conference has.

Merit

The workshop will present challenges, solutions, future directions in modeling, control, sensing and interaction control of continuum robots to the audience. It will also have an emphasis on medical and surgical applications to illustrate how theory is applied to real problems.

Impact

Due to the wide spectrum of topics ranging from kinematics, statics to estimation with surgical applications, the workshop will have broad impact on the mechanical engineers community. On the educational aspects, we expect to excite student interests in future directions in continuum robots and surgical robots.

Workshop Content

The workshop will discuss the three types of continuum robots: wire-actuate single backbone, concentric tube, and multi-backbone continuum robots. Wire-actuated continuum robots use wires to bend a central continuum backbone. Multi backbone robots use push-pull actuation of a multitude of beams to achieve their equilibrium shapes. Concentric-tube robots use concentric combination of pre-curved elastic tubes and the robot motion is achieved by the rotation and extension of the tubes with respect to each other. After a presentation of history and motivations for recent applications of continuum robots, the workshop will focus on multi-backbone designs which have found extensive usage for dexterity enhancement in many surgical applications including otolaryngology, transurethral bladder surgery and single port access surgery.
The main focus of this workshop is to review research works on modeling, control and applications of multi-backbone continuum robots. The workshop will consist of four parts:

1. Introduction to continuum robots: history and overview of continuum robot architectures. After presenting some of the early works [1–4], we will discuss applications of continuum robots with emphasis on recent surgical applications including single port access and natural orifice surgery.
2. Modeling of continuum robot statics and kinematics: selected modeling works on all three types of continuum robots with an emphasis on multi-backbone type will be presented. The works selected for concentric tube robots include [5–8] and the works selected for single backbone continuum robots are [9, 10]. We will present early works [11, 12] on kinematics and statics of multi-backbone continuum robots first, then will follow up with surgical applications using these robots, including [13–17]. We will primarily focus on mappings between joint space and configuration space and configuration to task space of these robots. Both simplified and exact statics models will be presented with a prelude to applications of screw theory to investigating the sensing capabilities of these robots.
3. Sensing and interaction control: we will cover recent advances in intrinsic wrench and contact estimation/sensing using a modeling framework for continuum robots with multiple backbones [11, 12, 18–20]. Interaction control will include stiffness modeling and active compliant motion control for continuum robots [21]. Finally, we will present a framework for hybrid force/motion control of continuum robots [22].
4. Actuation compensation and friction estimation for continuum robots: we will review methods for actuation compensation and estimation of intrinsic friction parameters including works such as [13, 23, 24]. We will also discuss kinematic error prorogation and calibration [25].

Workshop Outline

The workshop is designed for a 4-hour meeting comprised of handouts, lectures and discussion with the audience. The timeline we envision is as the following:

- **Part I - Introduction** 1:00 - 1:40 p.m. Presenter: Nabil Simaan
  History and overview of continuum robots [1–4]

  —— *Short break* —— 10 mins

- **Part II - Multi-Backbone Continuum Robots** 1:50 - 2:30 p.m. Presenter: Nabil Simaan
  Kinematics and statics modeling of multi-backbone continuum robots [11, 12] and their applications [13–17]

  —— *Short break* —— 10 mins

- **Part III - Steerable Canulas** 2:40 - 3:20 p.m. Presenter: Nabil Simaan
  Mainly focusing on kinematics and mechanics modeling of flexible canulas [26].
  If time permits, may also cover concentric tube robots [5–8] and
  single backbone continuum robots [9, 10]

  —— *Long break* —— 20 mins

- **Part IV - Sensing & Interaction Control** 3:40 - 4:20 p.m. Presenter: Nabil Simaan
  Intrinsic wrench and contact estimation/sensing [11, 12, 18–20],
  active compliant control [21], and hybrid force/motion control [22]

  —— *Short break* —— 10 mins

- **Part V - Compensation & Estimation** 4:30 - 5:00 p.m. Presenter: Long Wang
  Actuation compensation and friction estimation [13, 23, 24], and
  kinematic error prorogation and calibration [25]

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