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TECHNOLOGIES FROM THE ROBOTICS LAB OF PROF. NABIL SIMAAN

Surgical Robotic Applications:

Force Sensing

Stiffness Probing

Contact Detection and Localization

Compliant Motion

Force/Motion Control

Automated Tissue Exploration

ADVANCED ROBOTICS AND MECHANISM APPLICATIONS LAB

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Vanderbilt University

Vanderbilt is an internationally recognized research university in Nashville, Tennessee excelling in path-breaking discoveries, scholarship, and leadership in higher education. Partnered with the Vanderbilt University Medical Center, an independent health care facility dedicated to patient care, research, and biomedical education, Vanderbilt has made great strides in advancing the field of healthcare with its technical pursuits.

Who we are

The Center for Technology Transfer and Commercialization (CTTC) provides professional technology commercialization services to the Vanderbilt Community, so that we may optimize the flow of innovation to the marketplace and generate revenue that supports future research activities.

CTTC accomplishes this by **serving** as an efficient and effective conduit for the transfer of promising Vanderbilt intellectual property to industry; **contributing** to regional economic development by licensing locally and supporting new venture creation; and encouraging collaboration between academia and industry.

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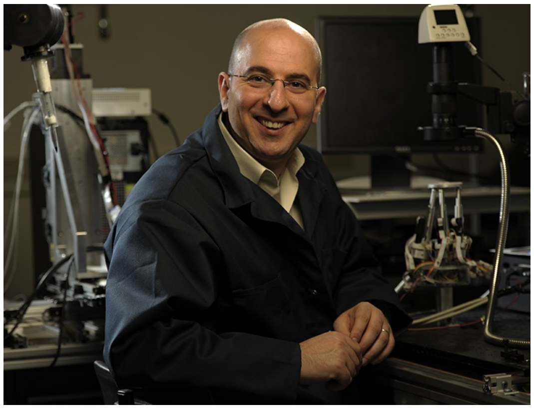
Professor Nabil Simaan, Ph.D.



Professor Nabil Simaan received his B.SC., M.Sc., and Ph.D in mechanical engineering from the Technion Israel Institute of Technology. His masters and Ph.D theses focused on the design, synthesis, and modulation for parallel robots with actuation and kinematic redundancies. In 2003, he pursued a position at Johns Hopkins University National Science Foundation Engineering Research Center for Computer-Integrated Surgical Systems and Technology as a Postdoctoral Research Scientist, focusing on minimally invasive robotic assistance in confined spaces. He continued his research at Columbia University as Director of the Advanced Robotics and Mechanisms Applications (ARMA) Laboratory until he joined Vanderbilt University in 2010 where he continues his work as Director of ARMA and as a professor of otolaryngology and mechanical engineering. Professor Simaan received the NSF Career award for young investigators, serves as an associate editor for IEEE Transactions on Robotics, and is the co-chair for the IEEE Technical Committee on Surgical Robotics.

Professor Simaan and his lab have years of experiencing working collaboratively with commercial entities of various sizes. His research is focused on advanced robotics, mechanism design, control, and telemanipulation for medical applications. His projects have led the way in advancing several robotics technologies for medical applications including high dexterity, snake-like robots for surgery, steerable electrode arrays for cochlear implant surgery, robotics for single port access surgery, and natural orifice surgery.

Surgical Robotics

Lead Inventor	Technology	Basic Research: Discovery and ideation	Feasibility: Invention and prototyping	Technology Development: Lab prototype validation	Technology Development: Animal model validation	Technology Demonstration: Clinical trials	Technology Demonstration: Regulatory process	IP Status: Patent
Simaan	Insertable Robotic Effector Platform Portfolio	Partnered	Partnered	Partnered	Partnered	Partnered	Partnered	Portfolio of Multiple Patents
Simaan	Low Cost Dexterous Wrists for Surgical Intervention	Seeking Partners	Seeking Partners	Seeking Partners				Issued US Patent 9,687,303
Simaan	Methods for Quick and Safe Deep Access into Mammalian Anatomy	Seeking Partners	Seeking Partners	Seeking Partners				Issued US Patent 9,549,720
Simaan	Compliant Insertion, Motion, and Force Control of Continuum Robots	Seeking Partners	Seeking Partners	Seeking Partners				Issued US Patent 9,539,726 and Continuation application 15/399,902
Simaan	Contact Detection and Contact Localization in Continuum Robots	Seeking Partners	Seeking Partners	Seeking Partners				Issued US Patent 9,333,650
Simaan	Minimally Invasive Telerobotic Platform for Transurethral Exploration and Intervention	Seeking Partners	Seeking Partners	Seeking Partners				Published US 20140316434 A1
Simaan	Continuum Robots with Equilibrium Modulation	Seeking Partners	Seeking Partners	Seeking Partners				US Provisional Application Filed

Click the technology title for a detailed summary of the technology

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Dexterous Robotic Wrist and Gripper for Extreme Precision Micro-surgical Maneuvers in Confined Spaces

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Summary

This invention presents a robotic wrist and gripper that operate with three independent degrees of freedom (yaw, pitch and roll) for increased dexterity in minimally invasive surgical procedures. This is the smallest robotic wrist of its kind, and due to its size and unparalleled dexterity, this wrist enables complex surgical maneuvers for minimally invasive procedures in highly confined spaces. Examples of surgical areas benefiting from use of this wrist include natural orifice surgery, single port access surgery, and minimally invasive surgery. In particular, the proposed wrist allows for very high precision roll about the longitudinal axis of the gripper while overcoming problems of run-out motion typically encountered in existing wrists. Thus this wrist is particularly suitable for extreme precision maneuvers for micro-surgery in confined spaces.

Challenges for Minimally Invasive Surgical Tools

- Many surgical sub-tasks such as passing a circular needle in confined spaces require localized orientation dexterity at the gripper. In particular, rotation about the longitudinal axis of the gripper is needed for facilitating passing circular needles in highly confined spaces.
- Existing surgical wrists do not offer three degrees of freedom wrists in a small package while allowing for independent control of roll about the longitudinal axis of the gripper. Instead, the motion of several joints are coordinated to achieve orientation dexterity. Perfect coordination to achieve very precise rotation about the longitudinal axis of the gripper is very difficult to achieve. Hence existing systems have difficulty achieving very high precision roll about the gripper's longitudinal axis.
- There are miniature surgical "wrists" capable of providing dexterity at the end of instruments used in minimally invasive procedures, but they are limited by the inability to roll about the primary axis as an independent degree of freedom

Technology Description

This revolutionary robotic joint greatly expands the capabilities of minimally invasive surgical tools by providing the dexterity to operate efficiently in tight spaces. The joint's dexterity comes from its ability to operate with three completely independent degrees of freedom: pitch, yaw, and rotation about its primary axis. The joint is especially suited for use with continuum robots during minimally invasive surgical procedures but has the potential to improve almost any tool, robotic or not, used in confined spaces.

Commercial Applications

Minimally invasive surgery is currently a $35 billion industry that is slated to grow by about 7% each year. Almost all minimally invasive tools and procedures would benefit from the advantages provided by this technology.

Unique Properties

- This is the smallest robotic joint of its kind
- The size and increased dexterity offered by this robotic wrist and gripper greatly expands the tasks that could be performed by a minimally invasive surgical robot or device
- This surgical wrist operates with three independent degrees of freedom, increasing the precision and dexterity with which it can operate in confined spaces

Intellectual Property Status

- Issued US Patent: US 9,687,303
- Published paper: IEEE/ASME Transactions on Mechatronics Vol. 18, Issue 5, Oct. 2013
- Nautilus Magazine: Team's tiny robot called medical science 'breakthrough'

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Flexible and Steerable Robotic Surgery System for Quick and Safe Deep Access into Mammalian Anatomy

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Summary

This technology uses a novel continuum robot that provides a steerable channel to enable safe surgical access to the anatomy of a patient. This robotic device has a wide range of clinical application and is a significant advance from the rigid tools currently used in minimally invasive surgical (MIS) procedures.

Challenges for Minimally Invasive Surgical Tools

- The rigidity of most instruments used in minimally invasive procedures limits their ability to access certain parts of the body and adapt to the natural movement of various tissue structures that occurs within the body during an operation
- This inflexibility leads to the need for an increased number of surgical access ports (more incisions) and increased risk of damaging healthy tissue during an MIS procedure
- The few surgical platforms that do offer flexible deep surgical access are mechanically complex and have a much larger outer diameter compared to the inner surgical channel, thereby warranting a larger incision and resulting in an unnecessarily bulky surgical device
- Existing access channels do not maintain parallelism of their distal tip despite changes in the shape of the access channel as it navigates the body. This complicates and lengthens surgical deployment time

Technology Description

This robotic system consists of a flexible channel that can be remotely steered deep into an anatomical cavity and then locked into place upon reaching the desired surgical site. The robot maintains orientation of its tip despite change in the shape of its flexible body such that it can be steered using a joystick and vision feedback. Once in place, the channel serves as a stable passageway through which users can deploy and guide other tools. The flexible, steerable channel increases the operating range for surgeons while preventing damage to healthy tissue during the procedure. The design allows for quick deployment while affording the surgeon with control of the orientation of the tip of the channel. During deployment, the channel flexibly adapts to anatomical passages. The design decouples changes in the shape of the flexible channel and changes in the orientation of its tip, thus affording surgeons with simple control of the orientation of the tip. Once deployed, the channel can be locked in a particular shape.

Commercial Applications

Over 57 million minimally invasive procedures are performed every year, and this surgical access robot is applicable to a large percentage of those procedures. Any procedure that seeks access to inner anatomy would be made safer and more efficient by the revolutionary capabilities of this system. The MIS industry grows by over 7% each year, but this robotic system promises to expand that growth even further by increasing the types of procedures that can be performed in a minimally invasive manner. Particular applications include trans-oral surgery of the throat, trans-vaginal, trans-anal, and colorectal surgery.

Advantages

- This steerable channel has a flexible body that gives surgeons freedom to maneuver around vital anatomy without damaging healthy tissue
- Once it reaches the target, the channel can lock into place so that other surgical tools can use the access channel
- The algorithms in place in this system hold the tip stationary as the body flexes, allowing the user to steer the tip simply with a joystick and visual feedback
- Due to its efficient design, the ratio between available bore and outer diameter is much smaller than similar devices, making this system much less invasive
- The design also decouples changes in the shape of the access channel from changes in the orientation of the tip.

Intellectual Property Status

- Issued US Patent: US 9,549,720
- Published Paper: Bajo, A., et al., (2012). IEEE International Conference on Robotics and Automation
- Video example: https://youtu.be/YSz3zZDdBKc?t=62

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Compliant Insertion, Motion, and Force Control of Continuum Robots

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Summary

Vanderbilt researchers have developed a framework for compliant insertion with hybrid motion and force control of continuum robots. This technology expands the capabilities of robotic surgery by providing continuum robots with the ability to autonomously discern, locate, and react to contact along their length and calculate forces at the tip, thus enabling quick and safe deployment of snake-like robots into deep anatomical passages or unknown environments.

Addressed Need

Minimally invasive surgical (MIS) and natural orifice procedures are limited by the absence of tools that can safely and precisely navigate the delicate passageways of the body. Passively compliant devices have the necessary flexibility to traverse some of these environments, but their inability to dynamically adapt to the curvatures of the passageways and lack of force control leave them an unsuitable option for many procedures. The present technology enables continuum robots to actively comply with external forces applied by the surrounding anatomy on the robot's body while analyzing the force at its tip, providing surgeons with the unprecedented ability to safely maneuver tortuous anatomical paths, explore unknown and constrained environments, and palpate and telemanipulate tissue with haptic feedback.

Technology Description

The novel combination of a hybrid force and motion control framework lays the foundation for full characterization of the interaction of the robot with its environment. This includes discerning collision, localizing contacts, estimating interaction forces, and autonomously complying with the environment along the entire robotic structure. Prior to insertion, a force threshold is set based on the properties of the surrounding tissues. This provides the robot with the necessary data to safely adjust its body shape to relieve the reaction forces upon contact with a force greater than or equal to the set threshold. At the tip, force sensors are integrated into an algorithm that yields force, shape, and stiffness estimation, ultimately creating a proprioception proxy previously unknown to continuum robot operators.

Unique Features and Competitive Advantages

- With this system, flexible robots can now take advantage of the benefits of flexibility while also possessing the stability to perform precise procedures
- The system is able to safely brace itself against the anatomy while ensuring that the tissue it contacts isn't damaged
- Bracing increases the stiffness and accuracy at the tool tip while ensuring that sensitive tissue isn't damaged for increased functionality
- Because the system keeps the robot from damaging surrounding tissues, the robot can be safely and rapidly deployed into unstructured or uncertain environments
- The force control algorithms provide a method for estimating forces at the tip which enables palpation, stiffness estimation, and shape estimation of unknown flexible environments

Intellectual Property Status

- Issued US Patent: US 9,539,726
- US continuation application: US2017/0182659/A1
- Copyrighted software for force control algorithms
- Motion Control Publications: IEEE Transactions on Robotics (Vol. 30, Issue 4), International Journal of Robotics Research (Vol. 34, Issue 4), ICRA 2013, Compliant Insertion Video Example
- Force Control Publications: International Journal of Robotics Research (Vol 35, Issue 4), Force Controlled Shape Exploration Video Example

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Compliant Insertion, Motion, and Force Control of Continuum Robots

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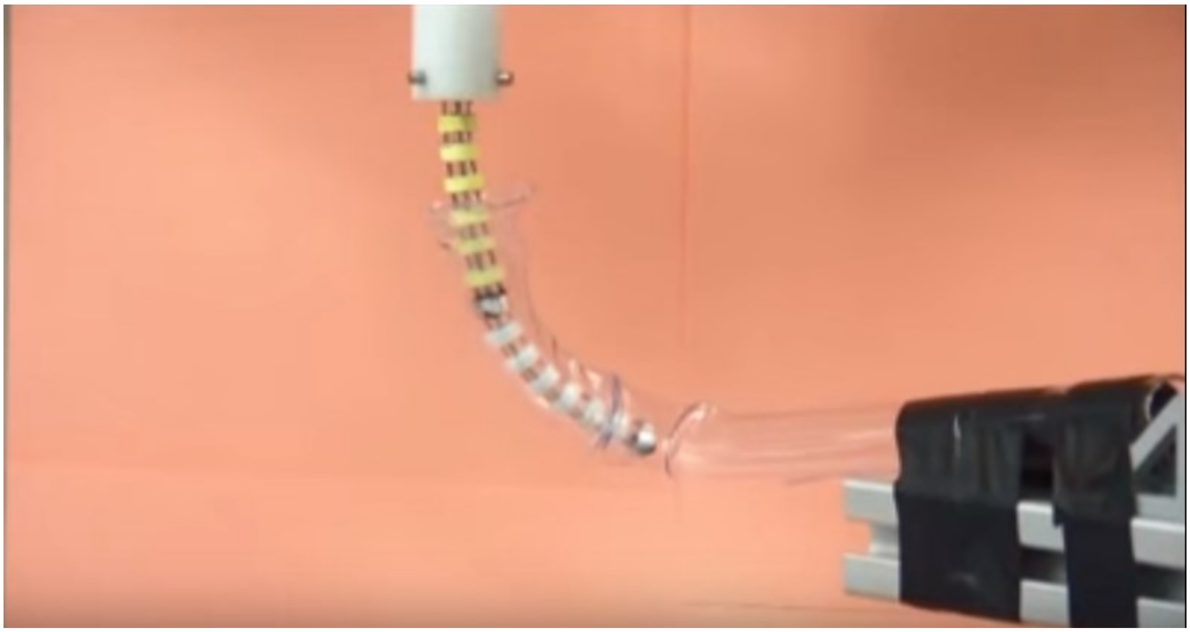

Fig. 1. An example of compliant insertion of a continuum snake robot into an unknown environment. Click image for a video demonstration.

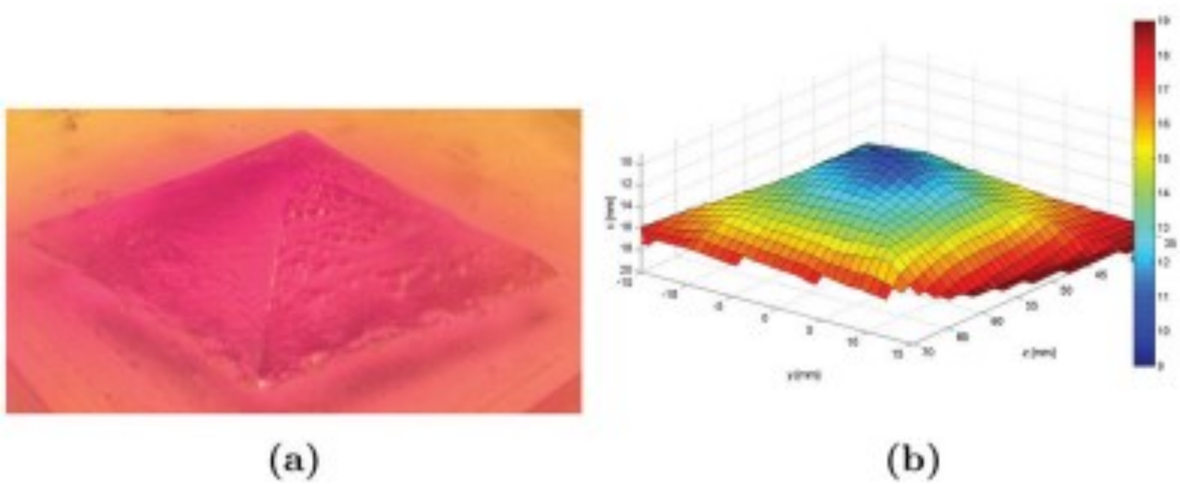

Fig. 2. An example of the force detection and estimation capabilities. (a) depicts the real shape of the object and (b) shows the estimated shape as detected by the robot.
Click image for a video demonstration.

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Contact Detection and Localization in Continuum Robots

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Summary

This technology expands the capabilities of continuum robots with a system and method that enables them to detect instances of contact and to estimate the position of the contact. This framework allows the motion of the robot to be constrained so as to ensure the robot doesn't damage itself, another robot arm, or surrounding environments. Applications for this technology include enhanced safe telemanipulation for multi-arm continuum robots in surgery, micro-assembly in confined spaces, and exploration in unknown environments.

Challenges in Robotics and Surgery

Minimally invasive procedures are usually performed using several tools and surgical ports; with several tools operating in such a small space, there are potential hazards associated with the tools running into each other, especially in a robotic procedure. To safely navigate uncertain surgical environments, a robot must be able to detect instances in which it contacts surrounding tissue or other surgical tools. There are previous works on contact detection, but these methods provide no information about the location of contact.

Commercial Applications

Robotic systems have shown exciting potential in their ability to perform minimally invasive surgical procedures with more precision than a human surgeon alone. Continuum robots are able to expand this potential by providing dexterous access along tortuous, long anatomical paths to deeper anatomy. This technology further expands the potential of these continuum robots by allowing them to operate deep inside unstructured environments through significant reduction of the possibility of damaging any tissue or surgical tool. The system can support applications in the area of natural orifice transluminal surgery, trans-anal surgery, and many other minimally invasive procedures. The system and methods also have industrial applications including the assembly of small parts inside electronic guide tubes, assembly in cluttered environments such as in car dashboards, exploration of sewage pipes, precise archeological procedures, and search and rescue exploration.

Technology Description

The framework enables an actively compliant continuum robot to detect an instance of contact and to localize that contact during a procedure. The system compares theoretical and actual positions of the continuum robot to identify a collision, and upon identifying contact, the robot can immediately move to relieve contact and ensure that no damage is done to the robot or surrounding environment. In surgical contexts, these contact methods also guide the continuum robot in safely bracing against the anatomy to increase precision and stability during a procedure, significantly broadening the complexity of procedures that can be performed by robotic surgical systems.

Technology Features

- Allows for both detection and localization of contact without perceptible delay
- Can be safely and rapidly deployed into unstructured environments
- Enables the continuum robot to safely brace itself against the anatomy while increasing the stiffness and accuracy at the tool tip, ensuring that the tissue it contacts isn't damaged

Intellectual Property Status

- US Patent Issued: US9333650
- Publication: IEEE Transactions on Robotics (Vol. 28, Issue 2, pgs. 291-302), Collision Detection Video Example

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Contact Detection and Localization in Continuum Robots

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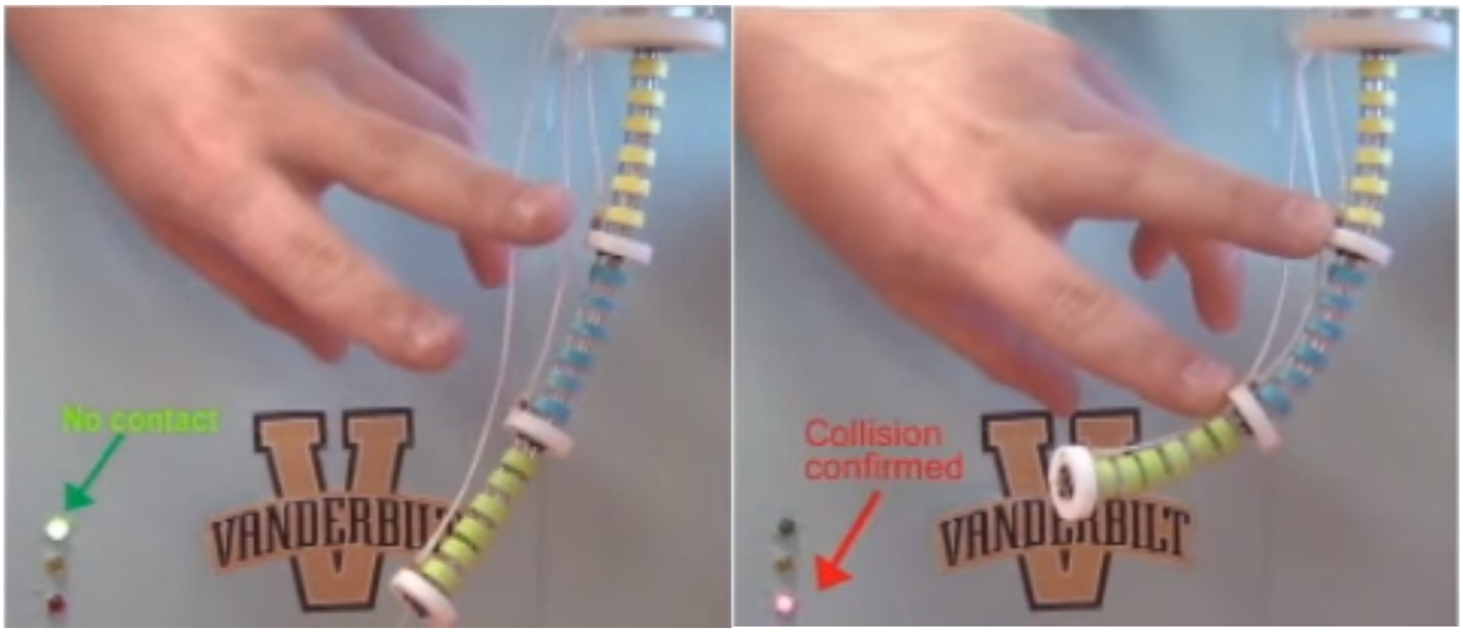

Fig. 1. A demonstration of the algorithm's ability to detect contact and adjust the robot's body shape accordingly. The left image depicts the robot in the absence of contact, and the right image shows the algorithm's response upon collision with the hand.
Click image for a video demonstration.

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Minimally Invasive Telerobotic Platform for Transurethral Exploration and Intervention

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Summary

This technology, developed in Vanderbilt University's Advanced Robotics and Mechanism Applications Laboratory, uses a minimally invasive telerobotic platform to perform transurethral procedures, such as transurethral bladder tumor resection and surveillance. This robotic device provides high levels of precision and dexterity that improve patient outcomes in transurethral procedures.

Challenges in Transurethral Procedures

- Visualization in the bladder is difficult with current technologies, and surface imaging is insufficient for locating the margins of tumors with underlying submucosal invasion
- Rigid tools that are currently used have trouble maintaining precision while following the complex curve of the bladder during resection
- Submillimetric precision is required during resection passes to avoid perforation of the bladder

Technology Description

This robotic system consists of an actuation unit that manipulates a central stem that can be extended the length of the urethral channel and into the bladder. A dexterous arm is inserted through the central stem that is also controlled with a high degree of precision by the actuation unit. The dexterous arm moves with the degrees of freedom necessary to perform procedures along the curved walls of the bladder and provide instrumentation channels that allow surgeons to incorporate a variety of surgical tools, such as a camera system, a grasper, or a laser ablation system, suited for the procedure at hand.

Commercial Applications

This device is useful for a wide range of transurethral procedures, most importantly those involving urinary bladder cancer diagnosis and treatment. Bladder cancer is the most costly cancer to treat per patient because of the high recurrence rates of tumors missed during surveillance, inaccuracy in tumor resection, and new tumor sites seeded during resection. Bladder cancer accounts for 1 in every 20 cancer diagnoses and there are over 70,000 new cases each year. Despite its prevalence, there are fewer therapies for bladder cancer than most other cancer types, and diagnostic tools remain relatively inaccurate, leaving bladder cancer with an unacceptably high rate of recurrence and misdiagnosis. This technology fills this gaping hole in treatment of bladder cancer while also showing promise for future expansion into a wider range of transurethral procedures.

Unique Features

- This robotic device provides the dexterity and precision necessary to operate effectively along the curvature of the bladder
- The dexterous arm is constructed so that several surgical tools can be used simultaneously reducing the time and complexity of a transurethral procedure
- The dexterous arm's mobility enables visualization of the entire bladder wall, with the use of a camera system, allowing for more effective cancer diagnosis
- The robotic precision of this device allows the surgeon to completely remove a tumor by resection without perforating the bladder, greatly reducing the potential for recurrence

Intellectual Property Status

- US Patent Application: US20140316434A1
- Publications: IEEE Transactions on Biomedical Engineering (Vol. 60, Issue 4), Ex-Vivo Evaluation of Telerobotic Transurethral System, Telerobotic System in Ex-Vivo Bovine Bladder Video Example

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Minimally Invasive Telerobotic Platform for Transurethral Exploration and Intervention

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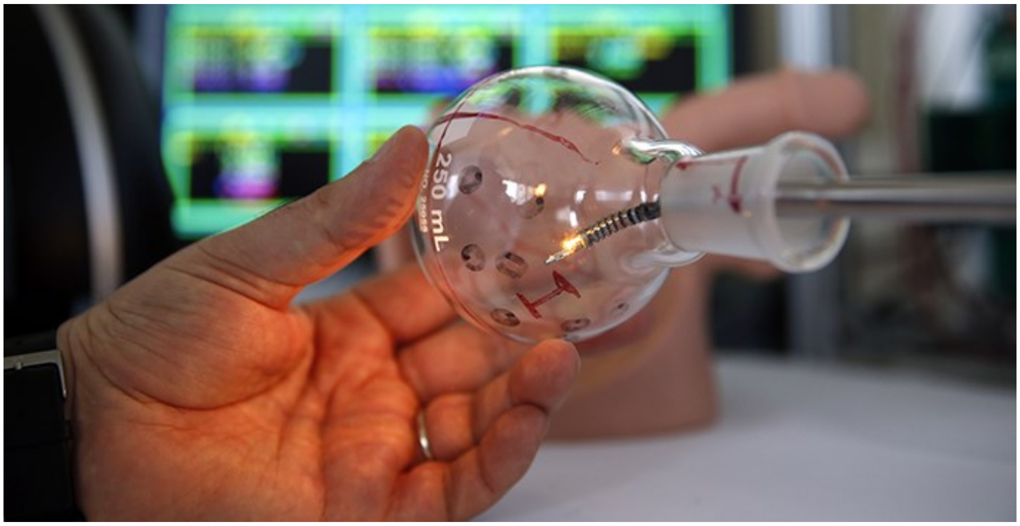

Fig. 1: The image above depicts the robotic platform's capabilities in terms of dexterity and flexibility. A flask is used as a proxy for the bladder to demonstrate the robot's ability to maneuver to and interact with the curved walls.

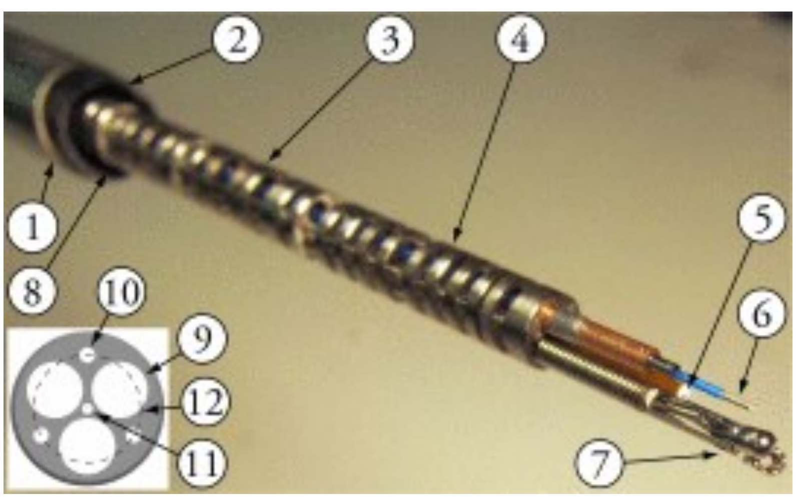

Fig. 2: An image of the surgical slave manipulator. 1) Resectoscope outer sheath. 2) Resectoscope inner sheath. 3) Proximal continuum segment. 4) distal continuum segment. 5) Fiberscope. 6) Laser cautery fiber. 7) Biopsy forceps. 8) Insertion tube. 9) Instrumentation channels. 10) Secondary backbone lumen. 11) Primary backbone lumen. 12) Pitch circle. Click image for video demonstration.

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Continuum Robots with Equilibrium Modulation (CREM)

VANDERBILT UNIVERSITY
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Summary

The A.R.M.A. Laboratory of Vanderbilt University has developed a novel continuum robot design enabling multi-scale motion at the macro and micro scale. The unique design allows miniaturization with minimal added cost thereby potentially giving rise to a new generation of surgical robots capable of both macro-motion for surgical intervention and micro-scale motion for cellular-level imaging or intervention. Micro-motion is achieved through a unique method for altering the equilibrium pose of the robot via material re-distribution throughout the length of the robot. This process ushers in a new class of surgical robotics termed continuum robots with equilibrium modulation (CREM).

Addressed Need

The prevalence of robotic slave arms in tasks requiring high accuracy and precision such as surgery is due to their superior dexterity compared to humans, yet these systems are still limited in their applications due to: i) the requirement of a large workplace environment, ii) the inability to reliably perform tasks at the micrometer scale, and iii) their inability to traverse curved passageways, which result in increased invasiveness in surgical contexts. The present continuum robot technology's novel method of equilibrium modulation can be used for both macro-manipulation as well as micro-manipulation on the scale of few micrometers without the need for reconfiguration of the system, expanding the capabilities of robotics in minimally invasive surgery (MIS) and industrial applications.

Technology Description

The technology revolves around continuum robots with equilibrium modulation. The flexible architecture of previous continuum robots allowed them to achieve snake-like motion for macro-manipulation. By placing small elastic wires inside the actuation tubes used for macro-motion and creating coordinated changes in the locations of these wires, the static equilibrium of the adjacent plates can be changed, creating motion at the micrometer scale while maintaining the ability to perform macro-motion. This embodiment is packaged into a miniature design allowing small confined spaces to be traversed and worked in with reliability and precision. Once in place, the robot can use its continuum modulation capabilities to support micrometer scale image-based inspection, biopsy, and micro-scale intervention.

Commercial Applications

Minimally invasive microsurgery will benefit greatly from this technology. A few examples of applications are in micro-anastomosis and microvascular surgeries, nerve repair and grafting, optical coherence tomography (OCT) guided surgery, tissue-level diagnoses, and inspection of microelectromechanical devices and microfluidics. Extensive testing is underway for the incorporation of OCT probes. The combination will broaden possible imaging environments and open new opportunities for ophthalmologic procedures, biopsies, and targeted drug delivery with real-time feedback of the progress.

Unique Features

- CREM robots are capable of both macro and micro-movement and manipulation without the need for modification to the system
- The present technology is able to achieve motion resolutions of 1 micron or less using inexpensive actuators
- The ability to traverse tortuous anatomical and industrial pathways and achieve high levels of precision will reduce the need for invasiveness in deep anatomical procedures

Intellectual Property Status

- US Provisional Application Filed

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Continuum Robots with Equilibrium Modulation (CREM)

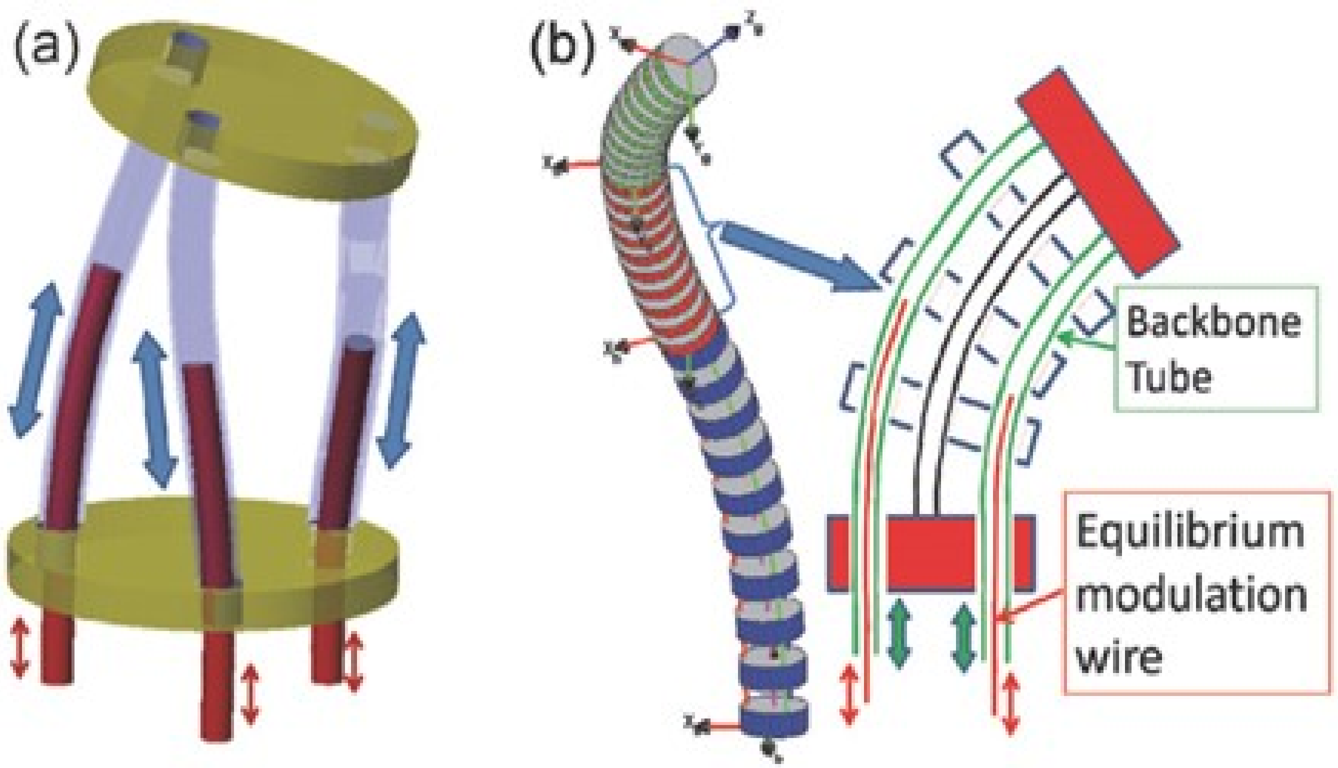

Figure 1. Image (a) A parallel robot using CREM (b) A continuum snake-like robot using CREM. Click on image for more depictions of prototypes and explanations of the technology by Professor Nabil Simaan.

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Vanderbilt Research Quick Facts

Vanderbilt University is ranked 15th among the best national universities.

Vanderbilt sponsored research and project awards total $672 million.

Vanderbilt University School of Medicine ranks 8th in NIH funding with $340 million.

The School of Engineering ranks 36th for graduate engineering programs.

Vanderbilt is home to one of the oldest Biomedical Engineering departments in the country, dating back to 1968.

The close proximity of the Vanderbilt School of Engineering and Vanderbilt University Medical Center enables a culture of interdisciplinary collaboration in research and education. The recent addition of the Engineering and Science Building (not pictured) in 2016 brings further opportunity for collaboration with seven floors of state-of-the-art research spaces and an Innovation Center.

For licensing inquiries please contact:

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