A review on Snake-like Continuum Robots for Medical Surgeries

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Abstract. This paper describes the various applications of Continuum robots in the field of medical science. These robots are biologically inspired by trunks and snakes. They possess the ability to transverse into small and restricted spaces, to manipulate objects in difficult environments and move in curved path. Due to this ability they can be extensively used in medical science as precision is very important in this field. Recently, increasing efforts have been made towards different surgical areas. In this paper recent state if structure, modeling and actuation in snake like robot is provided. Recently, increasing efforts have been made in various surgical interventions. In this paper, current state of structure, modelling and actuation in snake like robot is provided.

Keywords: Snake like robots, Robot assisted surgery, Continuum Robots, Hyper – redundant robots.

1. Introduction
Robotics is a field which is still in its initial and formation stages. Many designers are there who explore the different range of robotic structures which can actually sense objects, perceive the signals, navigate around the given workspace and have locomotion, they grasp objects and operate accordingly [8-10]. Various manipulators were produced and found at the very starting of robotics discipline. Till date, the core part of the robotics is the robotic manipulator which is being industriously and beneficially introduced in industrial markets all over the world. However, in the areas of vastly disciplined and controlled industries, the traditional rigid link robotic manipulators have been less successful, for example the factory floor [3]. The rigid-link structure (which are usually brilliant for precise and accurate end effectors’ positioning) causes unwanted collisions and uneven movements when not in work cell environments that are specially developed to maintain open area for their movements.

Various industries became successful in designing a snake arm robot that goes into the confined space. There are different examples of feasible robotic structures which include mounting of a snake like link, an industrial robot or design actuator [11]. The shape of the robotic arm is synchronized with the linear movements of the overture axis which eventually enables robot arm to follow the path to confined places.

There are different features that are associated with snake like robots.
- The constant change in diameter along the length of the robotic arm.
- They are self-sustaining and support their own joints.
- They are usually tendon-driven or controlled through pneumatic controls.

Variable curvature snake-like robots were also developed. But the kinetic modelling is difficult for these robots. The control required for continuum robot consists a great challenge because of the compliance of continuum robot. Different dynamic models for planar continuum robots are now present in robotic market [18]. The principle of virtual power is the main concept for the dynamics of all the spatial continuum robotic manipulators. The statics and dynamics of these robots of variable curvature have been presented by the classical Cosserat rod model. The design of a controller is still a very difficult issue because of the material flexibility and many other similar problems. A neural network controller and feedback control which is model is not present has been proposed and then tried that do not use constant curvature frameworks for forward kinematics.

Robotic engineering made notable impacts on human life over the decades. Apart from the process of revolutionizing manufacturing industries, the robotic manipulators have now emerged into different
applications in agriculture, aerospace, medicine and education. Robots are integrated into medical operational systems all around the world and upgraded minimally invasive medical procedures. [24] Minimally invasive surgeries are very useful as it can reduce patient’s pain, time of treatment and life risks. The use of Robotic engineering in surgeries brings a good amount of precision, instinctive ergonomic interface, and the ability to access all the inaccessible surgical locations remotely with miniaturized medical instruments. Snake like robots have potential to increase the advantages of minimally invasive surgery as they are scalable to miniature size, flexible to bend and can easily reach all the difficult access locations in human body. These robots complete their surgical tasks with high dexterity. In this paper I will discuss a major category of Snake like robot [12].

2. Literature Review
Kahrs, et al., 2015[1] discuss that in the last decade, that the application of robots in various surgeries have grown to a large extent. Medical robotics is a new and uncultivated engineering field that made the tremendous technical enhancements over the past few decades. Still the benefits that are potentially provided by medical robots are difficult to understand. By studying the existing market and delegate research systems, experts guess can be clearly made about the effect of robots on future medicine and surgeries. In the robotic system for surgeries, various approaches of independent, autonomous or semi-autonomous motion are present which are responsible for synergetic manipulations and fixtures. To keep the surgeon on target, these robots can be used as supervision tool.

Antman, et al., Springer Science, 2005 [4] discussed the important aspect is that the medical applications. For some surgeries accurate position localization of tissues present in surgical areas are required. Various systems such as intra-operative trackers for soft tissues by pathfinder, explorer or MRI/CT Scan machines with robot interfaces were developed for imaging. With the help of these imaging machines, localization data was easily retrieved. He also discussed about the most well-known surgical robot ‘da vinci’ which was developed by intuitive surgical corporation for invasive surgeries. ‘da vinci XI’ is the current 4th generation version of this product.

As discussed in the paper of Beasley, 2012. [5] and Maeso, et al., 2010 [6], the teleoperated robotic system of ‘da vinci’ helps the surgeon to manipulate the input devices in an environment where only immersive visualization is present. The inputs are converted in 3-D motion vision system known as endoscope as well as wrist operated laparoscopy instrument for surgery. The Laparoscopic surgery has now been providing numerous benefits to the patients for more than 20 years in comparison to open surgery. Surgeon performs various operation with the help of medical instruments in laparoscopic surgery. They can see the area of surgery by endoscopic cameras, which projects image to the monitor available nearby. Surgeries done by robotic assistance is thus considered as an important advancement in the field of medical science. Surgeons can perform operation with ease, he/she can view 3D image with high precision f surgical area. The enhancement of technology allowed the instruments to bend during a surgery, twist and rotate continuously more than conventional instruments or the wrist of surgeon.

Turchetti, et al., 2012 [7], discussed that with aging many physical and mental diseases attack human beings. They become more prone to these diseases due to increasing pollution and unhealthy lifestyle. This actually poses challenges for working population. Nursing and daily care profession will be required. Robotic systems such as NurseBot, which have significant capabilities to provide daily care to the people seeking help to live independent lives. These systems became more economical and established test beds for development of more multi-application robots. The Tele operated surgical robots provide highly developed instruments and flexible movement through small incisions that can be directly controlled by the physicians or surgeons.

Taylor, 2006 [8], discussed about the surgical endoluminal and diagnostic procedures which are driven by magnetic movement of GI tract present in anthro-morphic robot arm. Stereo Taxi Platform & Given Imaging Limited confirmed the peculiar approaches used for clinical applications towards magnetic locomotive. Paper presented details about a 6 DOF robot arm with capsular chip interacting with
permanent magnet. Highly precised movement can be attained through the robotic approach, which enables a reliable positioning of the endoluminal device. Though, usual surgical robots need high track in operation theatres and use articulating tip instruments which are rigid in nature. The inclination towards Minimal invasive surgeries with the help of Snake like robots is significantly evident on Fuchs, 2002[9].

3. Design Principles
Snake like robot is a movable manipulator whose flexible and constitutive structural design make tangential curves along the continuous vectors. Figure 1 illustrates the various categories of Snake like robots along with the type of actuation they require.

![Figure 1](image)

Figure 1. Illustrates the different categories of continuum robots and gives a source point with examples for the discussion below. Originally published under CCBY-NC-SA3. license; hydraulic [30].

3.1 Structural Design
Majority of Snake like robots that are used in medical applications are single backbone robots. These robots have a single elastic structure which is centrally located to support the route of actuation or transmission within the elements and to support the equipment for the body of manipulator. Different types of material have been used to design the backbone; some of them are springs, elastic rods and tubes, braided polymer tubes (for robotic catheters) and some moulded polymers. Design principles for any Snake like robot are the dedicated range of workspace and stiffness of the robotic structure. Designing optimization is achieved by the physically available unplanned design procedures that are dependent on the best practices for complicated and complex Snake like robots.

3.2 Actuation of Snake-like robot
The actuation has been differentiated in two categories. The first category is the Intrinsic actuation, in which the actuation is present inside the moving robotic structure itself. The second category is Extrinsic actuation in which the actuation occurs outside the main body and caused by force through external transmission system. Tendon cable, multi-backbone and concentric tube robots work with extrinsic actuation Whereas Pneumatic, shape memory and hydraulic robots work with Intrinsic actuation.

3.3 Modeling of Snake-like Robot
A productive research was done on the accurate modeling of Snake like robots for medical applications. The basic component present in any Robotic model is its Kinematic Structure that is required to represent the Geometrical orientation of the body of manipulator. Inverse Kinematics and
Control is an emerging field of study for Continuum Manipulators. The basis of approach for the controlling of Robots used in Surgeries requires proper strategy of prior section. The robots are either used as insertion devices or tele-operation robots. The majority of efforts in the area of medical applications have been focused on Forward kinematics and Dynamics.

4. Surgical Systems
This section comprises all the commercial and research Surgical systems those comprise Snake like robots for different applications. Figure 2 illustrates the common surgeries done through these robots.

4.1 Neurosurgery
It deals with the critical and delicate anatomy of the human brain. To improve the efficiency and success of treatment in this field, it is required to perform Neurosurgery with less invasive procedures. There are many risks involving areas such as tissue pull, cranium opening and regions deep within brain. Surgical Snake-like robotic systems have been developed to help the surgeons in Stereotactic ways. Snake-like robots enable new range of procedures for surgery, where regions within brain can be reached through curvilinear or nonlinear paths. The major areas of Neurosurgery are:
- Intracerebral Delivery of Drugs
- Intracerebral Evacuation of Hemorrhage

4.2 Otolaryngology
This surgery provides natural orifices to several regions of human body for a variety of surgical treatments. For the diseases present in those specific areas, conventional open surgery is performed. The missing dexterity can be achieved by using the Snake-like robots. The various surgeries of Otolaryngology are:
- Functional Endoscopic Sinus Surgery
- Transnasal Skull base surgery
- Surgery of the throat
4.3 Cardiac Surgery
Valve replacements, repairs or closure of septal defects require open heart surgery. These structural procedures are known as Cardiac surgery. A pulmonary bypass is used to perform surgical operations on a non-beating heart. Few Surgeries are performed on beating heart also through stabilizing the area of operation. Cardiac surgeries which require Catheter enables minimal invasive procedures with the help of small incisions.

4.4 Vascular Surgery
Common applications of Catheters and guide wires for performing vascular surgeries are angioplastics, embolization and aneurysms. The major problem for surgeons is to control steering as delivering the right amount of force and torque can be very challenging.

4.5 Urology
The well-known ‘da Vinci’ robot developed by Intuitive Inc has many applications in the field of Urologic Surgery. The futuristic platforms of these surgeries have the feature of Single port in order to increase precision and reduce invasion.

5. Gaps in Research
There are three grand challenges that are responsible for restricting the continuum robots to be commercialized for medical practice.

5.1 Instrument, its Visualization, and then the Integration of various instruments together
Main challenge for using snake like robots in medical field is to develop dedicated instruments according to the need in surgery. These instruments are difficult to build as the Physicians are dealing with human body. Now, Beyond the application of reaching to the different corners and moving on curved paths, the successful and efficient use of snake-like robots also need visualization of the basic anatomy for surgery. Many continuum robots have small diameter (usually less than 1 mm) which leads to the development of very small instruments necessary and then they are integrated into the end-effectors. Besides instrumentation and visualization, the integration of devices all together is still a major challenge. Different interfaces are introduced to make these devices compatible with each other.

5.2 The Human and Machine Interface
Physicians are gradually learning to operate there robots as in the end they have to use them, not the engineers. They are now able to interpose the insertion angles of the needles, depth and the location of the tip of needle (or other similar instruments) which is noticeable in the endoscopic images. The most important challenge is to provide the knowledge about the curvilinear shape of the robot manipulator, contact points, actuation speed and force acting on the structure of the operator.

5.3 Sensing of shape and force required
The three-dimensional shaping of continuum robots is an important challenge as it done in real time. The knowledge about all the shapes is the basic requirement for future advancement. It is also required for the human-machine interaction and different interfaces.

6. Conclusion
It is promising to note that interesting and impactful developments have been taking placing in the field of continuum robotics for the benefits of medical science. However, it is still in transition phase. There are several challenges that need to be addressed with further research and studies. Case in point is the compact size and compatibility of continuum robots that helps physicians in many ways. The size and compatibility factor are very encouraging from a medical point of view but these are issues which require large amount of research work such as sensing done by the robots, their control, and
their interaction with humans. There are some medical robots which are commercially available. Robotic surgeries are catching up very fast globally and also giving very good outcomes.

7. Future Work
We foresee that a next wave of revolution vis a vis uses of robotics in the next few decades and that would immensely benefit both patients and surgeons. Scaling is the key issue. Hence, the future work would be more focused on the inverse kinematics of continuum robots as very less work has been done so far in this area. Inverse Dynamics of continuum robots is often abandoned in medical applications, due to valid reasons. There are several factors responsible for that which include

- The frequency of relevant surgical motions is far lower than the modal frequencies developed due to the light weight of most of the surgical continuum manipulators.
- Elastic energy storage and friction dominates the actuator forces rather than inertial properties. In spite of these problems and challenges, there exists some potential for development and that can be leveraged by taking into consideration the inverse dynamics of these Continuum robots for some important and critical medical applications.

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