The 6th Joint International Conference on Multibody System Dynamics and
The 10th Asian Conference on Multibody System Dynamics
November 1-5, 2020, New Delhi, India

# Kinematic/Kinetic Formulation and Simulation Study for Hyper-Redundant Continuum Robot

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## Abstract

Hyper-redundant wire-driven continuum manipulators are very attractive to the scientific research community. They can be utilized in the nuclear industry, chemical plants or the medical field, all of which require them to work in a confined workspace and an extremely constrained environment. Their unique capability could help us reach new horizons of robot application.

Despite their advantages, continuum manipulators have lower accuracy than traditional rigid type robots because of their high structural redundancy [1]. To improve continuum robot precision, previous research has attempted to formulate its kinematics by assuming a piecewise constant curvature [2,3]. However, the curvature in actual robotic systems is not constant and depends on position and posture.

Actuation of continuum manipulators could either be indirect on power transmission (as pneumatic and hydraulic [4,5]) or direct through mechanical transmission (via tendon/wire/cable [6-9]). Among the actuation systems classified, wire-driven continuum manipulators will be potentially applicable in areas such as industry, medicine and agriculture. Wire-driven actuation is often used in applications in which substantial accuracy and payload capacity are required. There are two types of wire-driven continuum manipulators: hard continuum manipulators [10-11] and discrete hyper-redundant continuum manipulators [12-14]. The backbones of the former type are mostly made of elastic material (e.g. NiTi) and such a design allows it to bend at any point of the structure. The latter type of continuum manipulators can bend only at the joints because the spacer discs are interconnected by universal or ball joints. In this research, we deal with wire-driven discrete continuum robots classified as the latter type with a passive sliding backbone disc mechanism. Similar research with sliding spacer discs was conducted by Burgner-Kahrs et.al[15]. They developed a tendon-driven continuum robot with extendable sections using permanent magnets. The robot sections extend or contract by using an additional motor and another three motors to guide the manipulator bending. For extension, magnets move the discs by their repulsion force, while maintaining a certain distance from each other. However, in our proposed design, the manipulator does not extend or contract. Instead, the sliding mechanism is designed to make internal strain stress evenly distributed along the backbone structure.

Furthermore, Kang and co-workers also presented a similar robot interlaced continuum robot arm with a sliding spacer disc along the backbone in the principle of following a master[16]. However, the proposed design has a complicated structure mostly suited for inspection tasks only.

There are many kinematic models for continuum manipulators based on the robot structure. The most popular kinematic model is the constant curvature model, which simplifies formulation by assuming the robot backbone kinematics in a planar deformed state[17]. The great contribution on continuum robots kinematics was done by Hannan and Walker, who proposed kinematics applicable for concentric manipulators and hyper-redundant as well[18][19].

For the manipulators with pneumatic actuation, Ohno and Hirose method was proposed[20], and for the flexible backboned manipulators, Gravagne's method was proposed[21]. The derived kinematic model for wire-driven continuum robot arm was also proposed by Zheng Li et. al [22].

In this research, we conducted the motion simulations that combine kinematics with robot kinetics because the proposed continuum manipulator design with sliding spacer disc mechanism (Fig.1) requires torque/force equilibrium equations to determine the positions of sliding discs that passively slide along the backbone. It also formulates the way to control the tip-position, which is validated by the simulation study(Fig.2).

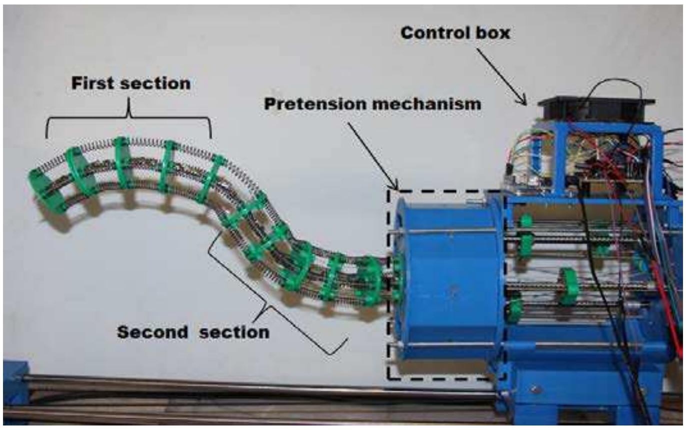

Fig.1 Overview of the continuum manipulator.

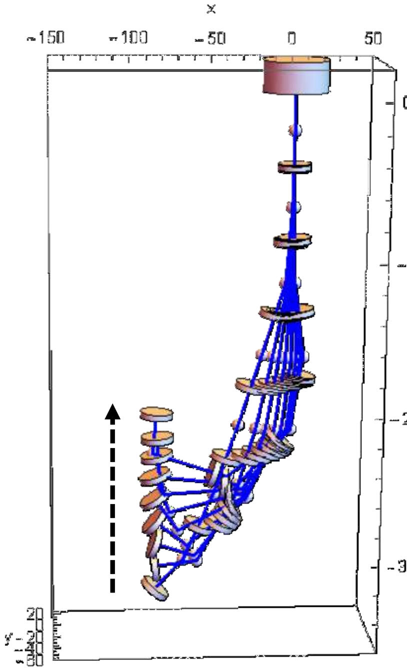

Fig.2 Example of Simulation study
: control of the end-point position

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