ME – PhD Thesis Colloquium

Modelling cable-driven continuum robots and their applications

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ABSTRACT

Flexible robots have been gaining traction in real-world applications over their rigid counterparts for their favourable features such as flexibility, compliance, better manoeuvrability, lightweight construction and ability to work in constricted environments in the presence of obstacles. Continuum robots, a class of flexible robots, are being widely used for their simplicity in design, ease of construction and operation. When actuated by cables, these robots, called 'Cable-driven Continuum Robots' (CCR), consist of a flexible backbone to which multiple disks are attached. Cables are passed through holes in the disk from the base till the tip, and when pulled, the flexible backbone and the CCR can attain different shapes based on their cable routing and backbone configuration. This thesis focuses on kinematics modelling of CCR for various configurations and provides a few of their applications.

Firstly, the forward kinematics of the CCR are explored. Due to its geometry, the CCR with a straight routed cable can be discretized into sections, which can be considered as imaginary four bars. With the geometry of the actuated CCR, the pose of the CCR was obtained by minimization of the 'coupler angle' of this imaginary four bar. This was then extended to multiple straight-routed cables and both single and multiple generally routed cables by assuming a second imaginary four bar, enabling us to track motion in 3D. A method based on the minimization of strain energy is then proposed, which is equivalent to the minimization of coupler angles. The strain energy-based method is extended to generally routed cables by appropriately adding terms due to torsion. This approach is also applied to a CCR with a pre-bent backbone (without any pre-tension). The proposed optimization-based method is geometry-based, requiring only the Poisson's ratio and the cable actuation length as the input parameter. This method is verified experimentally using multiple 3D-printed CCRs, showing good agreement between the simulations and experiments. The method is also compared to the Cosserat rod model and is shown to provide equivalent accuracy in prediction while taking lower simulation times for most cases.

Due to the nature of the optimization-based approach, the behaviour around obstacles inside the workspace of a CCR can easily be modelled with the addition of inequality constraints. This also enables the prediction of the location of contact by the observation of Lagrange multipliers associated with the inequality constraints – a byproduct of the minimization. A method is devised to predict the static force exerted by the obstacle on the CCR based on the principle of virtual work. The predicted contact location and the contact force are in good agreement with experiments performed with a 3D printed CCR and a load cell.

The optimization-based forward kinematics is used to solve two different inverse problems – to achieve a desired final shape of the backbone upon actuation, what should be (a) the general cable routing or (b) the initial shape of the backbone? The latter algorithm is used to design a three-fingered gripper to grasp a desired object, ensuring optimal grasp and multiple points of contact.

The aforementioned forward kinematics model is used to train multiple neural networks to solve the inverse kinematics of CCR with varying cable routings and geometry for single straight routed cable. The inverse problem for general cable routing – finding the cable routing to achieve a desired end effector position is also explored. Later, a comparison is provided between the optimization and neural network approaches for the inverse problems.

ABOUT THE SPEAKER

Soumya Kanti Mahapatra earned his Bachelor's degree in Mechanical Engineering from the Heritage Institute of Technology, Kolkata, in 2016, followed by his Master's degree in Machine Design from the Indian Institute of Technology (Indian School of Mines), Dhanbad, in 2018. He is currently pursuing his PhD at the Indian Institute of Science, Bangalore, under the guidance of Prof. Ashitava Ghosal and Prof. B Gurumoorthy in the Robotics and Design Lab at the Department of Mechanical Engineering. His research interests lie in the fields of kinematics, dynamics, robotics, and machine learning.