Monocular Shape Sensing for Continuum Robot

Thomas Enxu Li, Jimmy Chengnan Shentu, Vicky Chaojun Chen
University of Toronto

Motivation

- Continuum Robot refers to the subcategory of robotic manipulators that do not contain rigid links or identifiable joints. Precise motion control of continuum robots requires real-time and accurate shape sensing.
- Model-based shape sensing methods are sensitive to unknown external loads, and sensor-based methods take up valuable space in the robots and pose challenges to miniaturization.
- Existing visual-based shape sensing methods utilize two or more cameras to attain high accuracy, but such conditions may not be achievable in real-world applications.
- We investigate the feasibility of monocular visual shape estimation for a continuum robot in terms of accuracy and computation time.

Related Work

- Burgner et al. achieved a mean error of 0.473 ± 0.353 mm using segmentation and epipolar geometry analysis [2].
- Dalvand et al. achieve a maximum measurement error of 0.5 mm for the tip position and length and 0.5 degrees for the bending and orientation angles using a stereo vision system and a 3D reconstruction algorithm [3].
- Croom et al. achieve an average error of 1.53 mm using a stereo-visions-based self-organizing map [4].

New Technique

Problem Formulation: Assume we are given an RGB image of the robot, $I_{RGB} \in \mathbb{R}^{H \times W \times 3}$ and a binary occupancy mask of the robot, $O \in \mathbb{R}^{H \times W}$. The goal is to find the position of the robot in 3D, parameterized by the 3D coordinates of $M$ evenly-spaced points on the centerline of the robot, denoted as $P \in \mathbb{R}^{M \times 3}$.

Evaluation

- Shape sensing for continuum robots has typically been evaluated in terms of mean error of robot shape (MERS) and mean error of tip tracking (METE).
- We also report the runtime of each approach in terms of frames per second (FPS).

Experimental Results

Dataset

- We collected a custom dataset using an existing simulator. The simulated tendon-driven continuum robot is 280 mm in length and 10 mm in radius with a protective sleeve.
- 50,000 randomly sampled robot configurations are rendered with the Visualization Toolkit (VTK), where we save 512 x 512 RGB and depth images along with camera configuration and ground truth robot shape. Texture was added to make the dataset more realistic.
- 80% of the dataset are for training and validation and the remaining 20% are reserved for testing.

References