A Learning-Based Inverse Kinematics Solver for Two-Segment Continuum Robot Models

Jiewen Lai, Bo Lu, and Henry K. Chu
Department of Mechanical Engineering, The Hong Kong Polytechnic University
jw.lai@connect.polyu.hk

Abstract

In this brief work, we present a learning-based method to solve the inverse kinematics of a two-segment continuum robot manipulator. A simplified model featured with variable-length virtual links is proposed, which can better estimate the robot configuration needed to reach a point with the end-effector. A multilayer perceptron (MLP) is implemented to learn the mapping relationship between the configuration and the task spaces.

I. Motivation

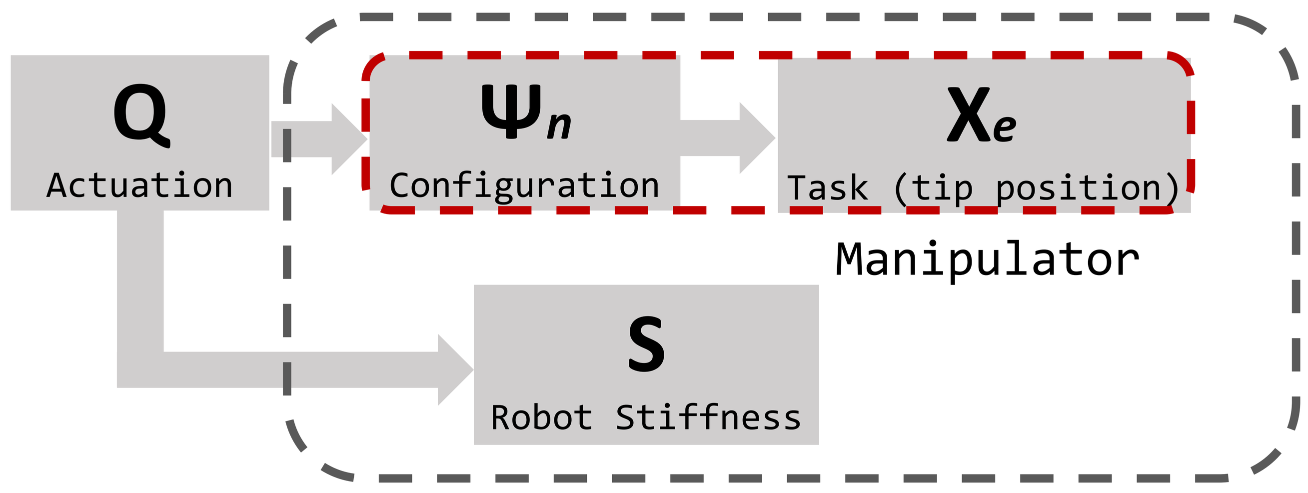

Fig. 1. System mapping.

The continuum robot is assumed to be a soft-bodied robot system, with its body made of highly compliant soft material. Unlike conventional robots, the kinematics of the robot system can be decomposed into three domains: task (tip position), configuration (shape), and actuation (motor inputs). The tip's position in the task space can be expressed as a function of robot configuration. For control purpose, the inverse is required, i.e., $\boldsymbol{\Psi}_n = f^{-1}(\mathbf{X}_e)$.

II. Method

a. Geometric Model of a Multi-segment Continuum Robot

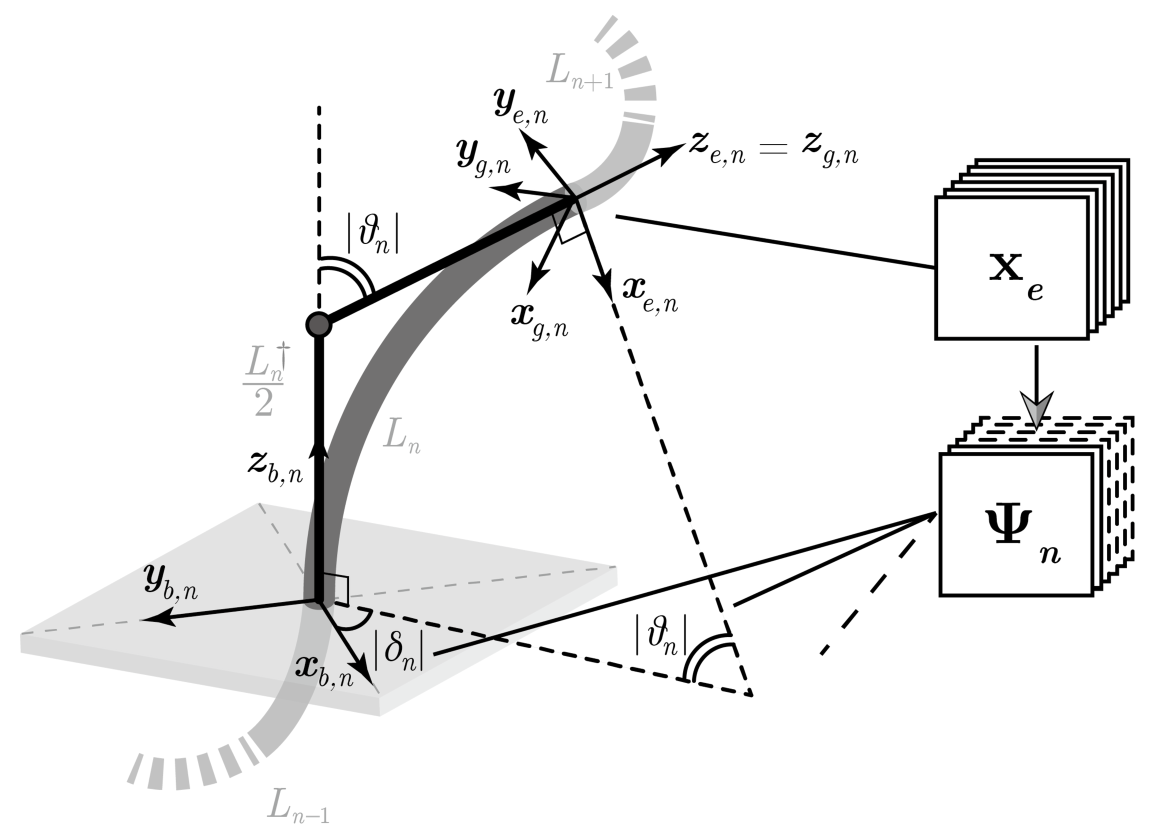

Fig. 2. Robot modeling.

Based on piecewise constant curvature assumption, the manipulator can be simplified as an articulated robot with several revolute joints as shown in Fig. 2. Consider the n-th segment of the continuum manipulator with a length of L_n, the configuration of this segment can be defined by δ_n and ϑ_n, where δ_n represents the angular deviation in terms of bending direction of the n-th segment w.r.t. the base frame of segment n, and ϑ_n denotes the extent of bending in such direction. By doing so, the configuration of a continuum segment can be interpreted as a 2-DOF articulated robot with two virtual rigid links with equal length of $L_n^*/2$, which is given by $L_n^*/2 = L_n \tan(\vartheta_n/2)/\vartheta_n$. Thus, the configuration and the end-effector status of an n-segment continuum robot can be described as:

$$\boldsymbol{\Psi}_n = [\delta_1, \vartheta_1, \ldots, \delta_n, \vartheta_n]^{\mathrm{T}} \in \mathrm{R}^{2n}$$

$$\mathbf{X}_e = [x_e, y_e, z_e, \alpha_e, \beta_e, \gamma_e]^{\mathrm{T}} \in \mathrm{R}^{6}$$

b. Learning the Inverse using MLP

The proposed inverse kinematics solver is trained to attain the nonlinear relationship between $\mathbf{X}_e$ and $\boldsymbol{\Psi}_n$ based on the forward kinematics using MLP. Levenberg-Marquardt (LM) optimization is employed in backpropagation for its fast convergence in non-linear fitting problems. The topology of MLP – the number of hidden layers N_H and the number of neurons N_N in each hidden layer - is determined based on the performance (mean squared error). Without loss of generality, a two-segment continuum manipulator is used to evaluate the method and verify the learning-based IK solver via simulation.

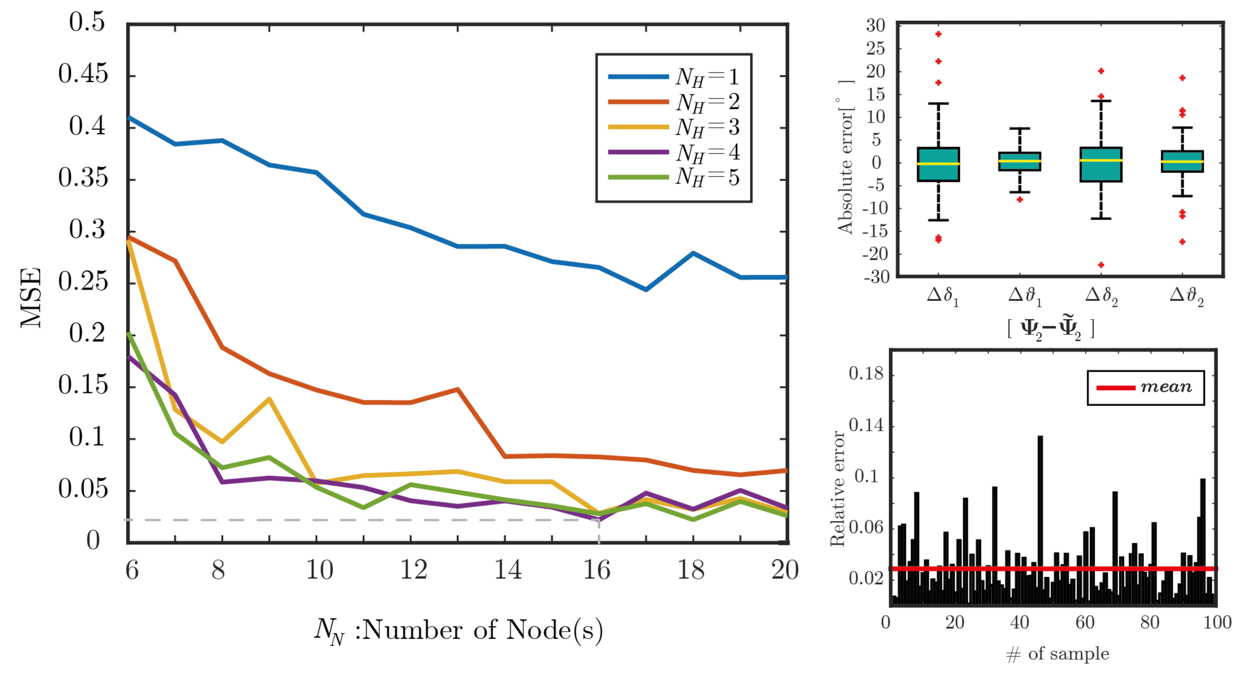

Fig. 3. MLP training performance.

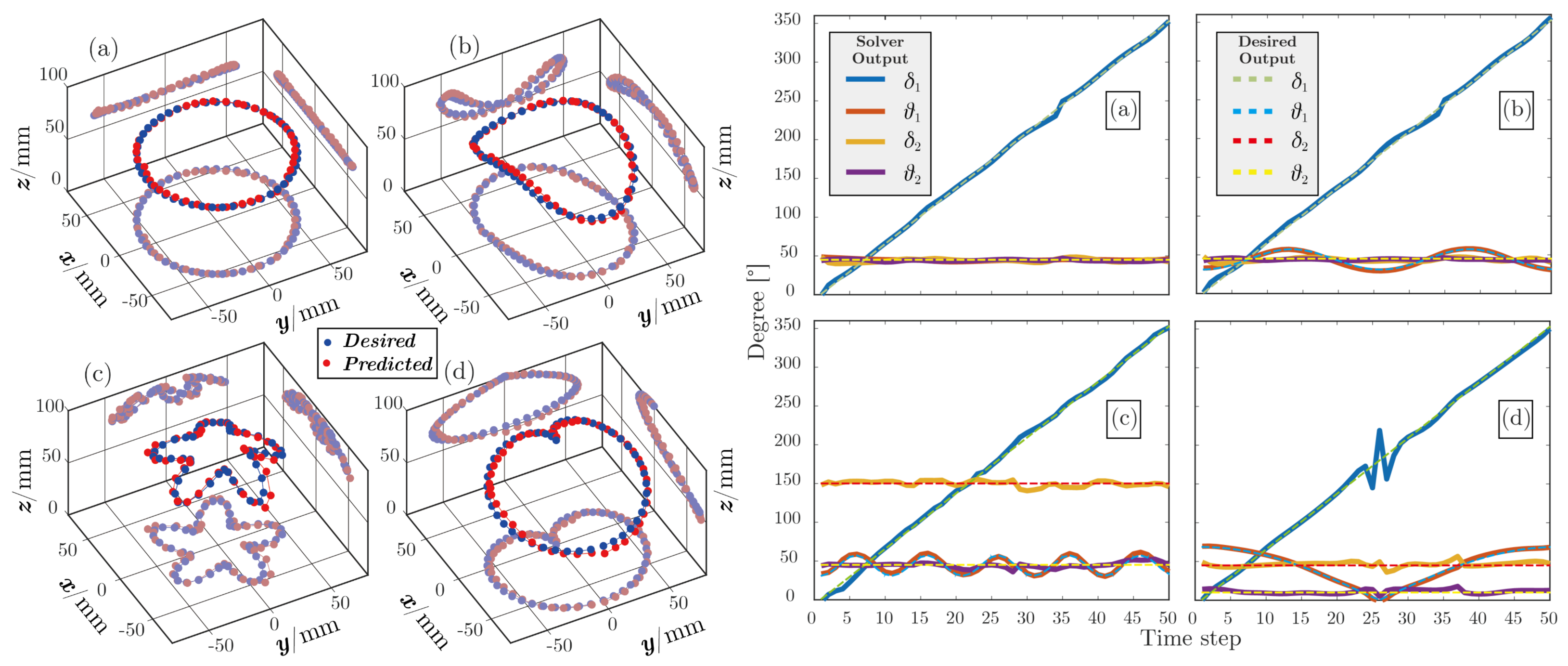

Fig. 4. Solver implementation in simulation.

III. Setup

A two-segment wire-driven soft continuum robot is developed to verify the proposed IK solver. The length of each segment is 50 mm, with a diameter of 8 mm. A color-based visual measurement system is built to track the segment gestures and end-effector pose in real-time for evaluation.

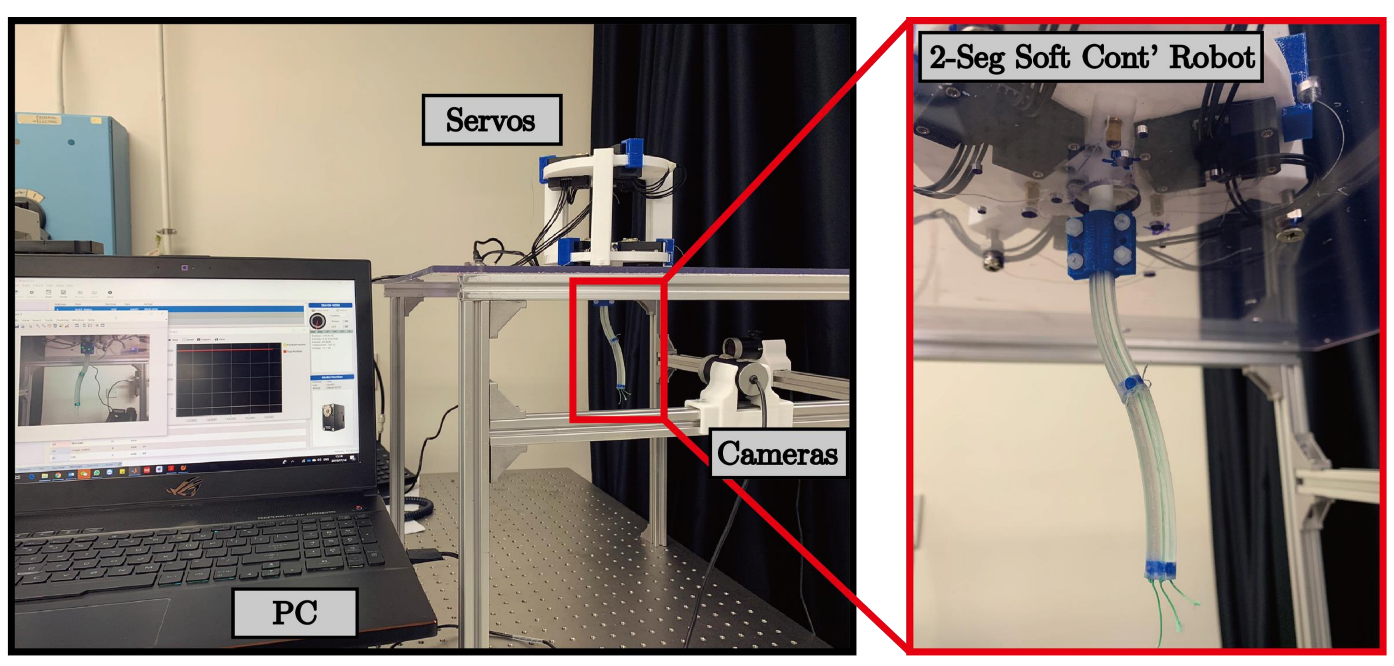

Fig. 5. Validation in prototype.

IV. Summary

- A learning-based solver is proposed to inversely solve the configuration by only knowing tip position;
- A simplified model is proposed to better estimate the relationship between the configuration space and the task space;
- Data are collected through simulation and used to train the learning-based solver;
- The herein study helps to evaluate the required manipulator configuration to perform tip path tracking.