Rigid robotic transformations with variable link lengths can approximate the kinematics of soft fingers with 'bones'

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INTRODUCTION

- The control of the endpoint location of a **traditional rigid robotic hinged finger** is well established but still requires **high precision** to manipulate objects well, especially when applying additional constraints to the system. **Soft fingers** decrease the precision required for control by **passively conforming** [2]. However, controlling their kinematics accurately remains an open problem on account of their (technically) **infinite degrees of freedom (DOFs)** [3]. **Semi-soft fingers** pose a **practical compromise**, where the **links are rigid** but the **joints are compliant** (as in anatomical joints and Swanson silicone implants) [1].

Goal

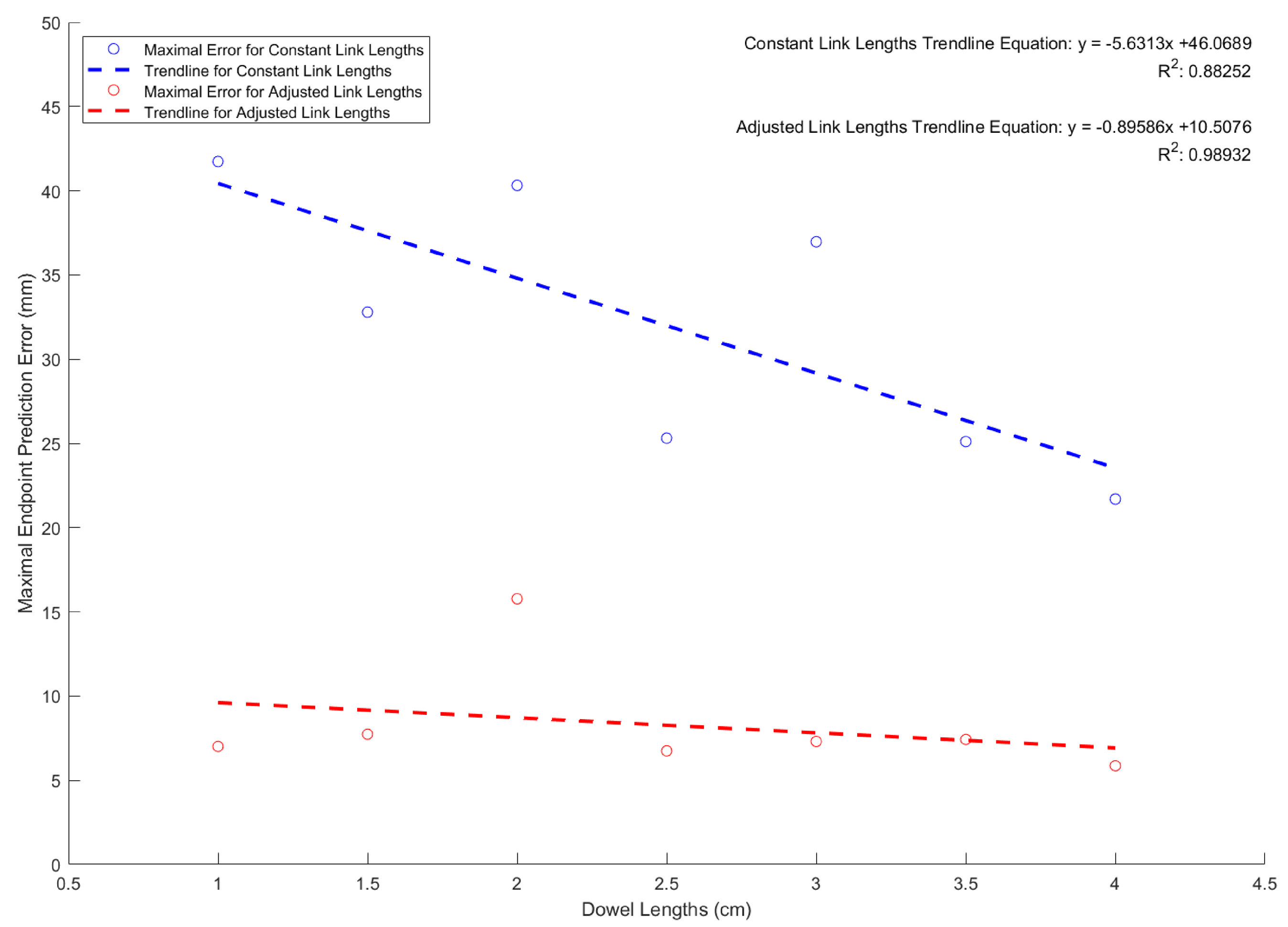
To test how well **traditional rigid robotic transformations** can approximate the **kinematics of a semi-soft robotic finger** (i.e., rigid 'phalanges' embedded in soft material), we made seven **tendon-driven, semi-soft fingers** of varying lengths to test the **relationship between finger softness and the accuracy of endpoint prediction** to explore their future utility and select proper segment lengths in **semi-soft hands**.

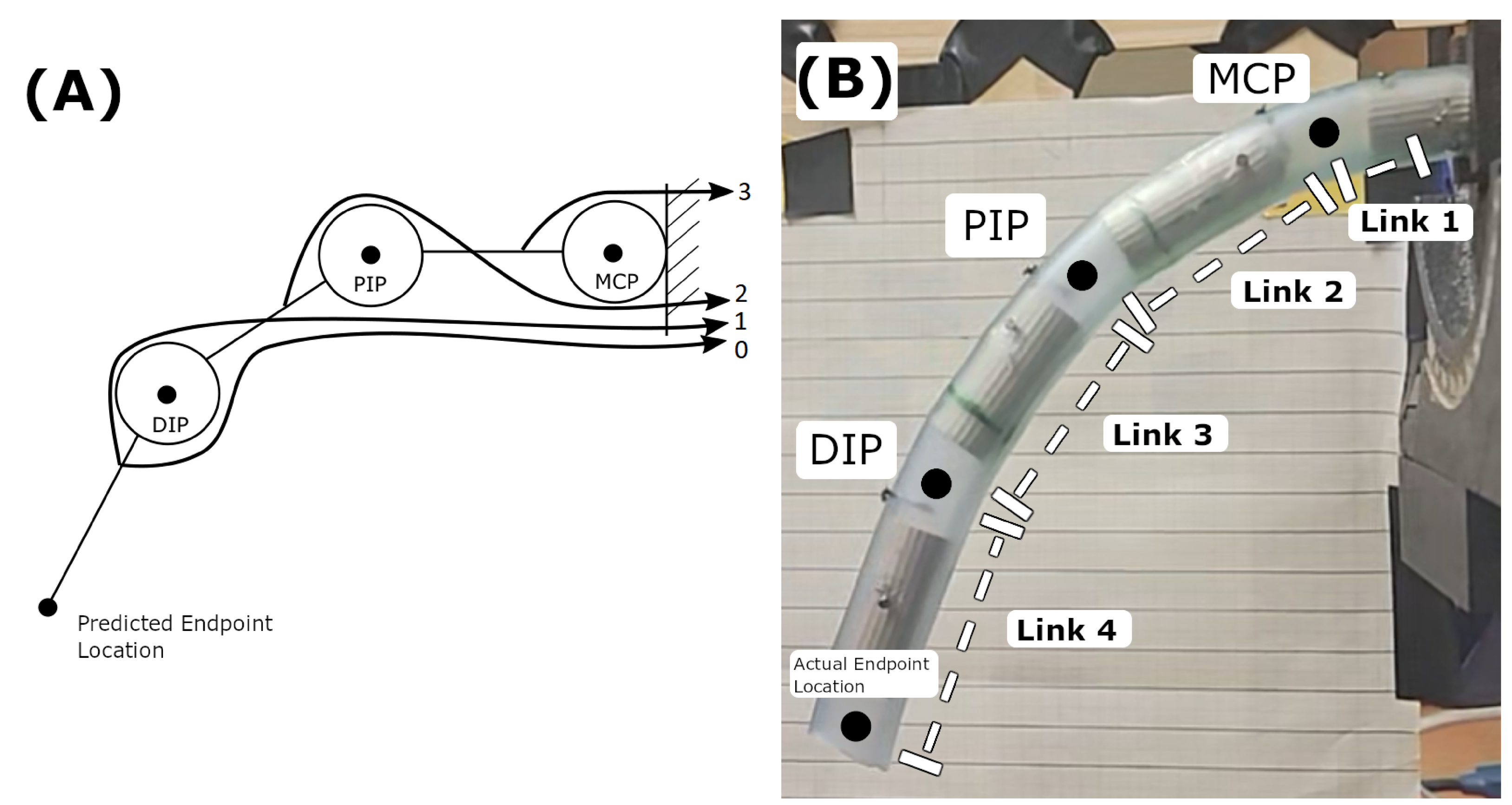
MATERIALS AND METHODS

- The **tendon-driven, semi-soft fingers** were constructed with a **length of 20 cm** and **three phalanges of length 1cm to 4cm** in increments of **0.5cm** (plus a *'metacarpal'* for mounting) with midpoints of phalanges being spaced **6cm** apart, serving as the *'joints'*
- **Tendons** were routed per the **N+1 design**[5] where **N is 3 degrees of freedom**, in which tendons **cross**, and therefore **affect multiple joints**.
- **Brushed DC Motors pulled on tendons** with **16 activation sets** to drive the finger to **different flexion-extension positions**.
- The resulting **finger endpoints**. were measured **at each position** using the **DeepLabCut motion tracking software** [4].
- We calculated the maximal error in the planar location of the endpoint (Euclidian distance between actual and predicted) under the model of **constant link lengths** and **compressible link lengths**.

RESULTS

We found that the kinematic model that assumes **link length compression** best predicts endpoint location. This kinematic model has a **maximum prediction error** between **5.20 mm and 15.78 mm** – a **74% error reduction** on average, as compared to the **constant link length** model. Detailed results show that the constant link length model's error is larger throughout the whole movement.





DISCUSSION

As the **inner diameter** of the PVC tube is **12.7 mm**, our results indicate that **semi-soft fingers** can be a **good compromise** to fully rigid or fully soft fingers as they retain the ability to **conform to object shape** while allowing **relatively accurate endpoint location predictions**. These results open up exciting possibilities for well-controllable, yet compliant, robotic hands that approximate the utility of the human hand, which is itself semi-soft.

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