Learning-based Estimation of Forward Kinematics for an Orthotic Parallel Robotic Mechanism

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Paper link

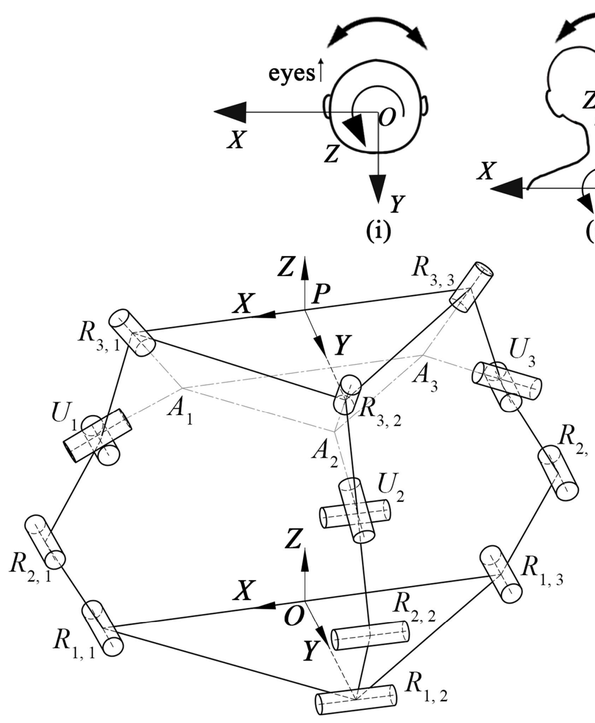
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Motivation and Background

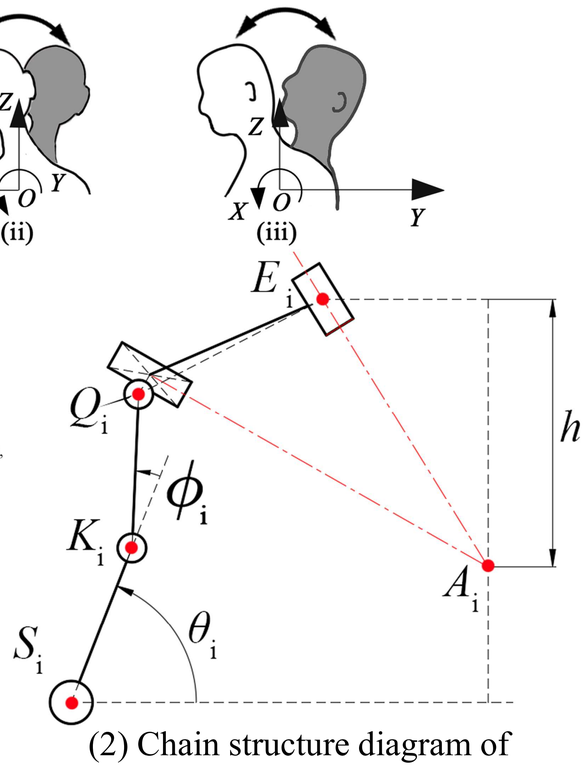
- Cervical spondylosis, a common source of neck pain, has been significantly affecting people over 30 years of age [1].
- Parallel robots are particularly well-suited to deliver appropriate motion support while employing a compact structure.
- Operating a parallel robot poses great challenges because of the complexity of its forward kinematics [2] and the often-times complete absence of closed-form analytical solutions.
- Our work aims to employ data-driven methods to solve the forward kinematics based on solutions obtained from inverse kinematics.

Design of a 3-RRUR Parallel Robot

- A three-chain Revolute-Revolute-Universal-Revolute (3-RRUR) parallel robot is designed and fabricated to provide traction support for patients. The use of the RRUR structure is motivated by the need to enlarge the workspace compared to the Revolute-Prismatic-Universal-Revolute (RPUR) structure [3].

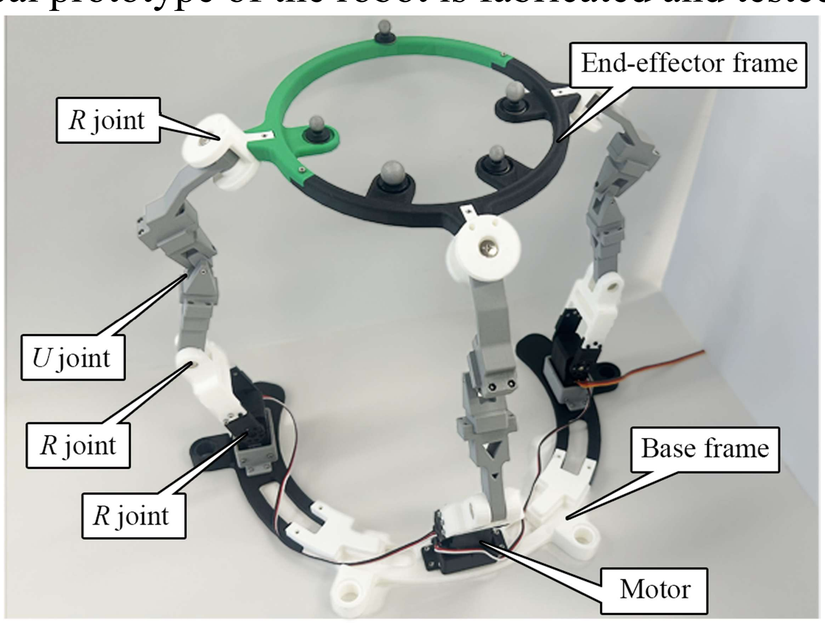


(1) Diagram of the developed 3-RRUR parallel robot



(2) Chain structure diagram of 3-RRUR parallel robot

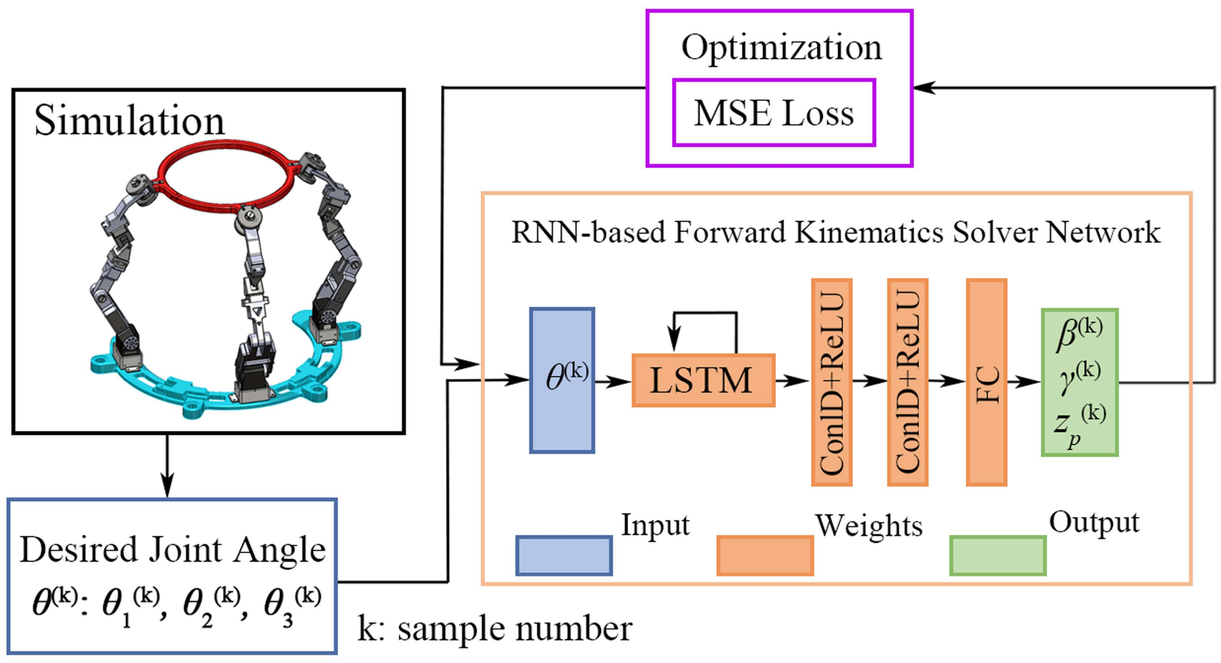
- The Koopman operator and an RNN are deployed to solve the forward kinematics in simulation. To the best of the authors' knowledge, this is the first attempt to utilize the Koopman operator on a 3-RRUR parallel robot.
- A physical prototype of the robot is fabricated and tested.



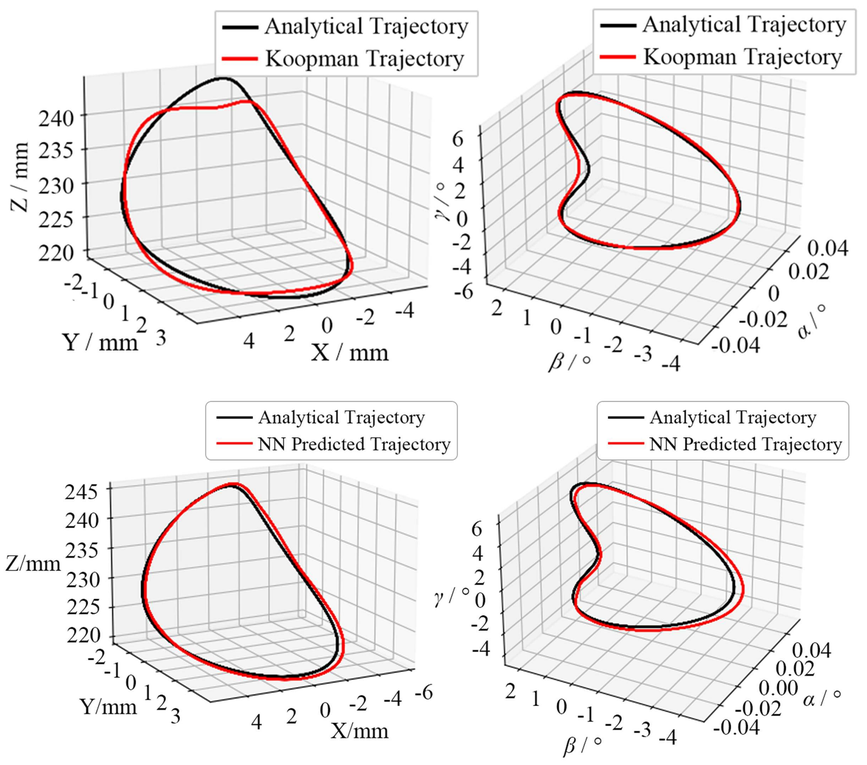
Koopman-Based Kinematics Estimation

- The Koopman operator efficiently learns the system's dynamics by lifting the original states to a latent space and capturing the flow of the lifted states (observables) with a finite number of linear functions.
- Herein, the Koopman operator is utilized to learn the mapping from the motor angles, θ_1,θ_2,θ_3, to end-effector angles β and γ, and translation z_p. The x- and y-translations can be then computed by geometry constraints.

RNN-Based Kinematics Estimation



- A trajectory of end-effector poses was generated from inverse kinematics as the ground truth, which serves as a benchmark to evaluate the performance of both methods.
- Dataset size: 248,790.



(1) Simulation results from the Koopman Operator

(2) Simulation results from RNN

Contributions

- A 3-RRUR parallel robot is designed to provide traction support for patients who suffer from cervical spondylosis.
- To address the challenge in forward kinematics analysis, a Koopman operator-based method and an RNN-based method are introduced to resolve the forward kinematics of the robot.
- The prediction accuracy from the RNN-based estimator is noticeably higher than that of the Koopman operator, while the Koopman operator can be much more quickly and easily deployed and updated online, without the need for large computational resources.
- A fabricated prototype of the proposed 3-RRUR parallel robot was designed to validate the results of the same trajectory presented in the two data-driven methods.
- This work offers a basis to support porting data-driven methods into robotic orthotics.

References

[1] A. I. Binder, Bmj.
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[3] J. Zhou, et. al, Robotica.