Real-Time Rehabilitation Tracking by Integration of Computer Vision and Virtual Hand

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Introduction

- **Finger Rehabilitation**: Essential for restoring fine motor skills impacted by neurological disorders.
- **Tracking Challenge**: Conventional systems for tracking rehabilitation are costly, clinic-dependent, and lack precise joint torque feedback [1].
- **Proposed Approach**: A vision-based system extracts MCP, PIP, and DIP joint torques using computer vision and simulation models and track the rehabilitation.
- **Impact**: Enables remote, low-cost, and accurate rehabilitation tracking to optimize exoskeleton assistance.

Methodology

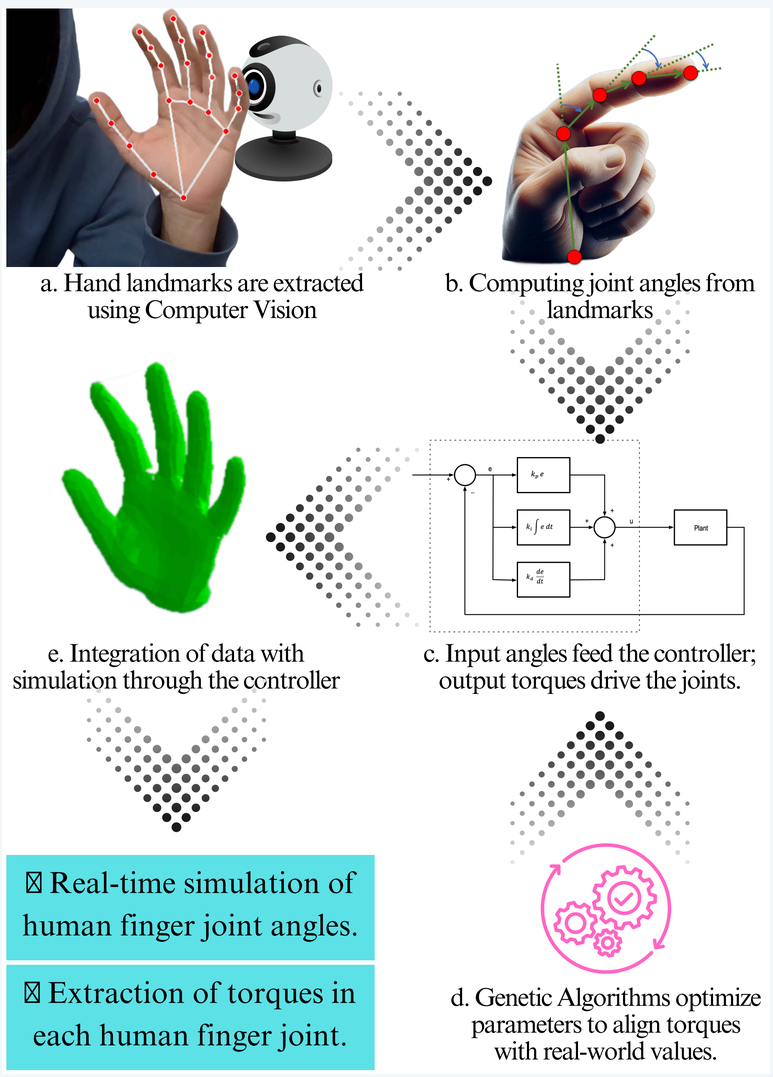


Figure 1: Framework of the Proposed System. The system integrates hand gesture recognition (a), pose estimation (b), torque computation (c), and optimization (d) to simulate and control the virtual hand model (e), with extraction of human hand finger joint torques.

Joint Angle Calculation:

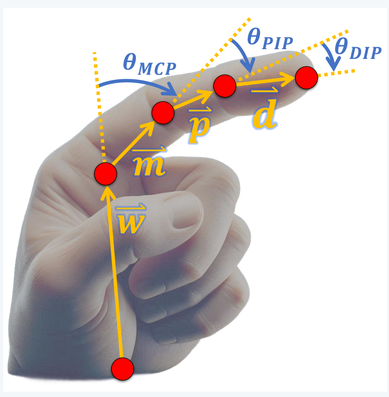


Figure 2: Illustration of the MCP, PIP, and DIP finger joints, highlighting their angular configurations, anatomical locations, and directions.

Then the angles of finger joints are extracted:

$$\theta = \arccos\left(\frac{\mathbf{v}_1 \cdot \mathbf{v}_2}{\|\mathbf{v}_1\| \, \|\mathbf{v}_2\|}\right)$$

Results

The system parameters are optimized using validation data from Agarwal et al. [2].

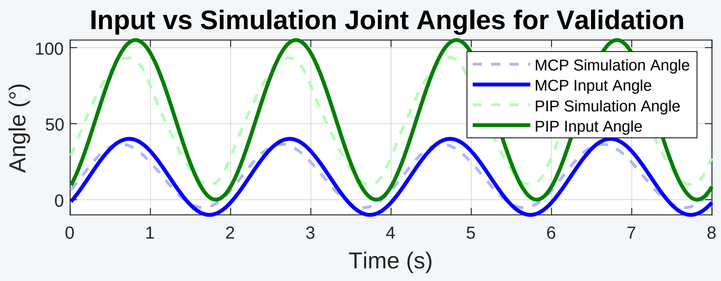


Figure 3: The input angles from the validation data and the joint angles from the simulation over four cycles within an eight-second interval.

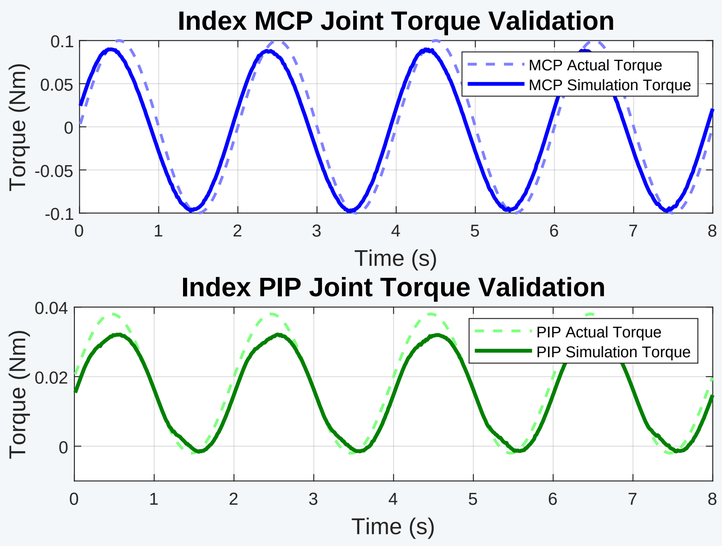


Figure 4: Comparison of torque measurements of validation data with simulated torque outputs for the MCP and PIP joints. The simulated torque, derived from the input angles shown in Fig. 3, represents the controller's output and corresponds to the torque extracted from the human finger joints.

Parameter	MSE	Δ Max
MCP Torque	4.35×10^{-4}	1.01×10^{-2} N·m
PIP Torque	1.51×10^{-5}	5.90×10^{-3} N·m
MCP Angle	8.65×10^{-3}	6.04×10^{-2} rad
PIP Angle	6.36×10^{-2}	2.01×10^{-1} rad

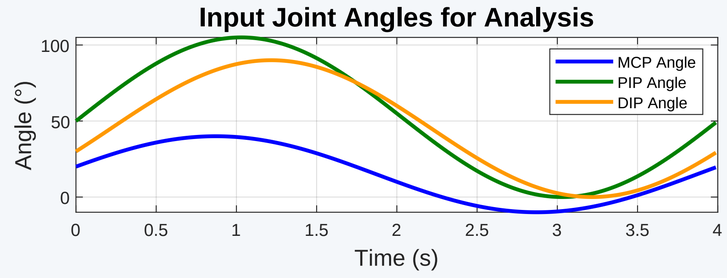


Figure 5: MCP, PIP, and DIP joint input angles over one oscillation in 4 seconds for extracting torques of different fingers.

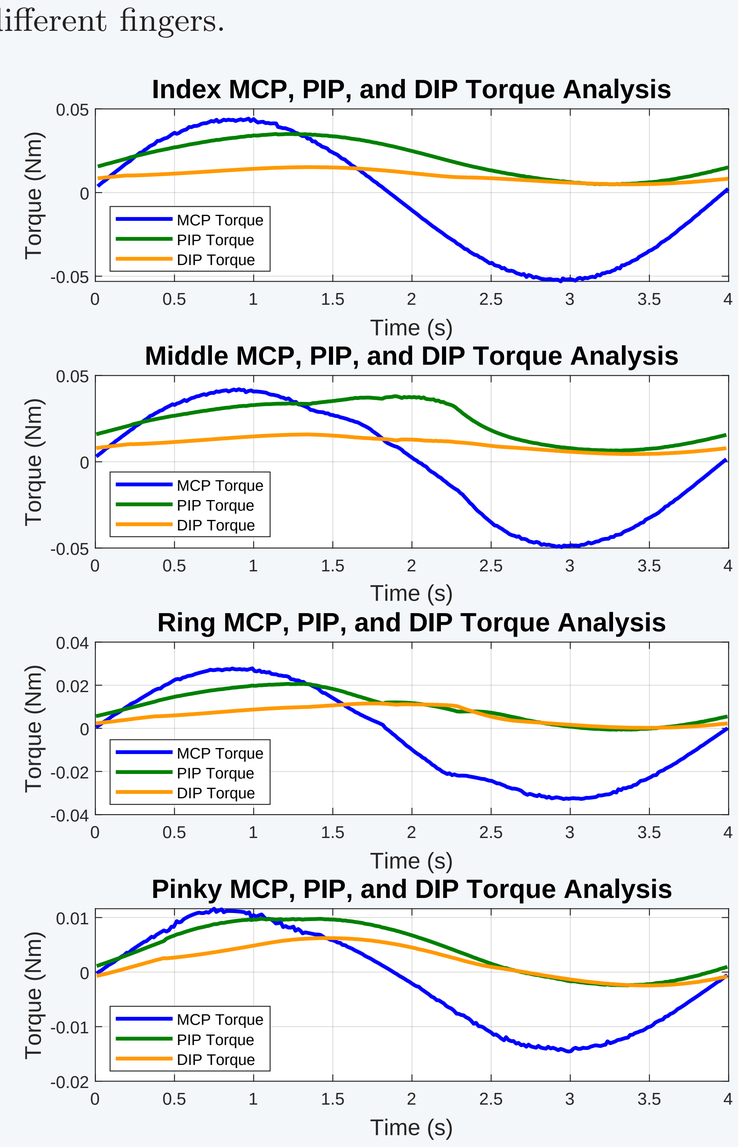


Figure 6: MCP, PIP, and DIP joint torques analysis based on the input angles in Fig 5 for index, middle, ring, and pinky fingers.

Discussion

- **Potential Impact**:
  - **Personalized Rehabilitation**: Using real-time tracking of finger joint torques allows for more tailored and efficient rehabilitation.
  - **Remote Monitoring**: Patients can be monitored remotely, reducing the need for frequent in-person clinic visits.
  - **Prosthetic design**: Torque data informs actuator selection and material optimization for natural hand movement replication.
  - **Robotic control**: Supports development of human-like control algorithms and reinforcement learning for assistive devices.
- **Future Directions**:
  - Improve the accuracy of hand tracking and motion estimation.
  - Single-camera occlusions may affect tracking; plan to integrate multi-camera setups and AI-driven occlusion handling and track more joints to achieve more data.
  - Integrate real-time adaptive feedback mechanisms for better optimization of system parameters.

References

[1] Steven C Cramer, Lucy Dodakian, Vu Le, Jill See, Renee Augsburger, Alison McKenzie, Robert J Zhou, Nina L Chiu, Jutta Heckhausen, Jessica M Cassidy, et al. Efficacy of Home-Based Telerehabilitation vs In-Clinic Therapy for Adults After Stroke: A Randomized Clinical Trial. *JAMA Neurology*, 76(9):1079–1087, 2019.

[2] P. Agarwal, J. Fox, Y. Yun, M. K. O'Malley, and A. D. Deshpande. An Index Finger Exoskeleton with Series Elastic Actuation for Rehabilitation: Design, Control and Performance Characterization. *The International Journal of Robotics Research*, 34(14):1747–1772, 2015.