Using Tactile Sensing to Inform Low-Cost, Force-Feedback Haptics

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Introduction

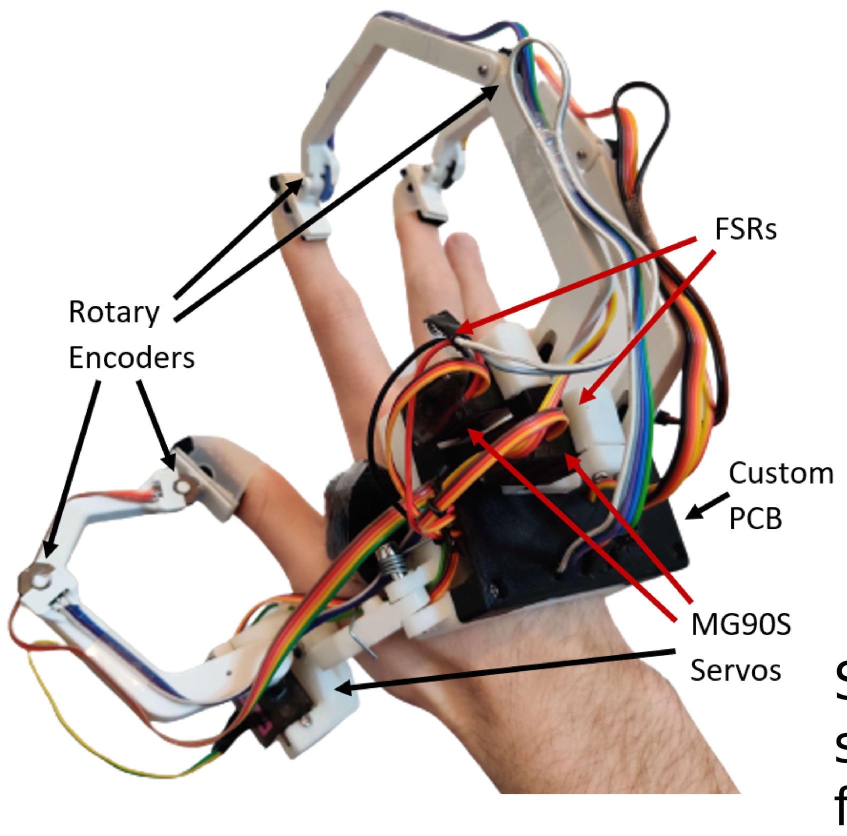
Widespread adoption of haptic technologies is hampered by high cost and low accessibility [1]. This work considers the use of TacTip optical tactile sensors, mounted on a Model-O robotic gripper (the T-MO [2]), in informing force-feedback (FF) haptics provided by a low-cost, open source haptic exoskeleton, called Remote Feelings (RF) [3].

Key contributions include:

- Redesign and construction of RF, adding finger tracking and reducing cost.
- Estimation of contact force from tactile images.
- Bilateral teleoperation framework with T-MO and RF.

Remote Feelings Haptic Exoskeleton

• Forces are measured with force sensing resistors (FSRs) embedded in the servo housings.
• Rotary encoders added to exoskeleton joints to allow calculation of finger pose with forwards and inverse kinematics.

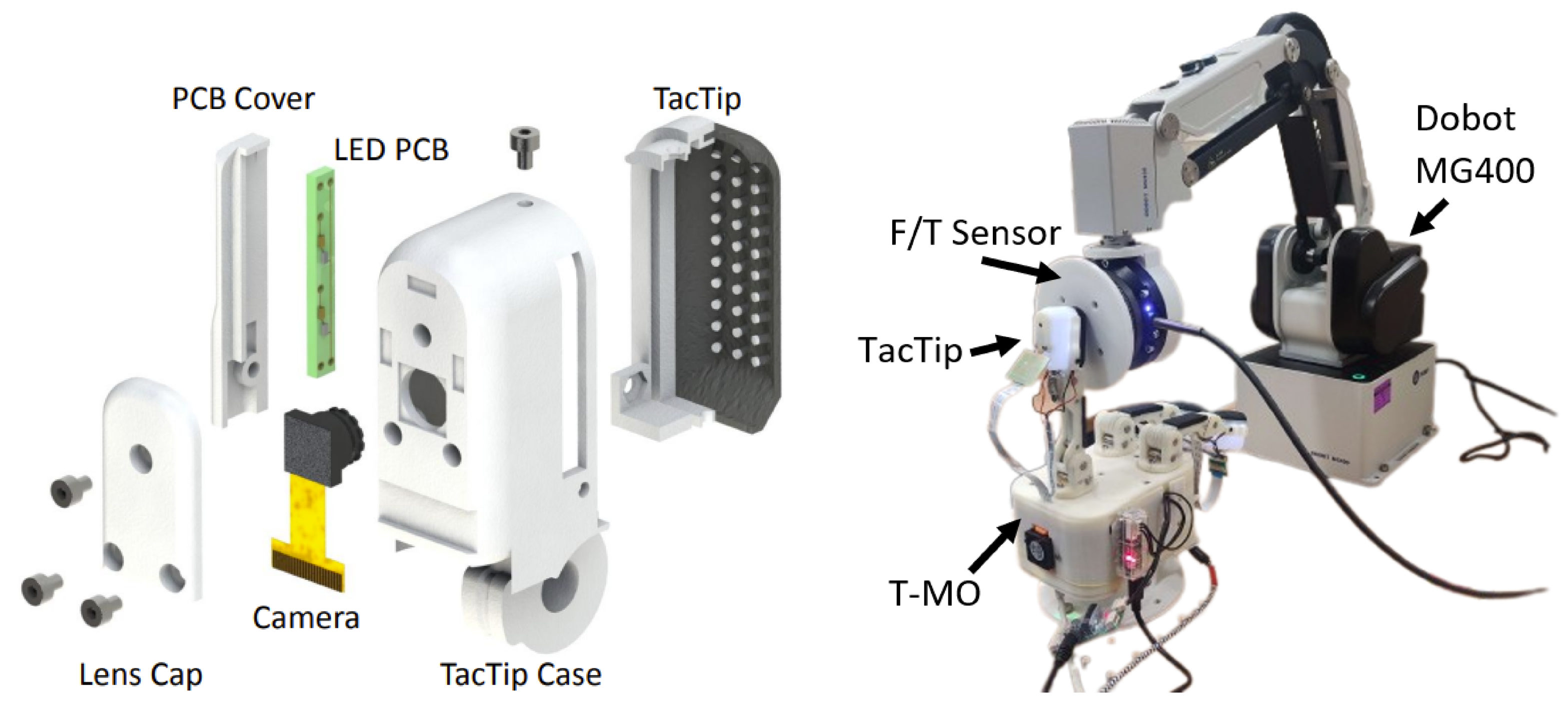


Step response of fingertip force to sudden, constant artificial contact force.

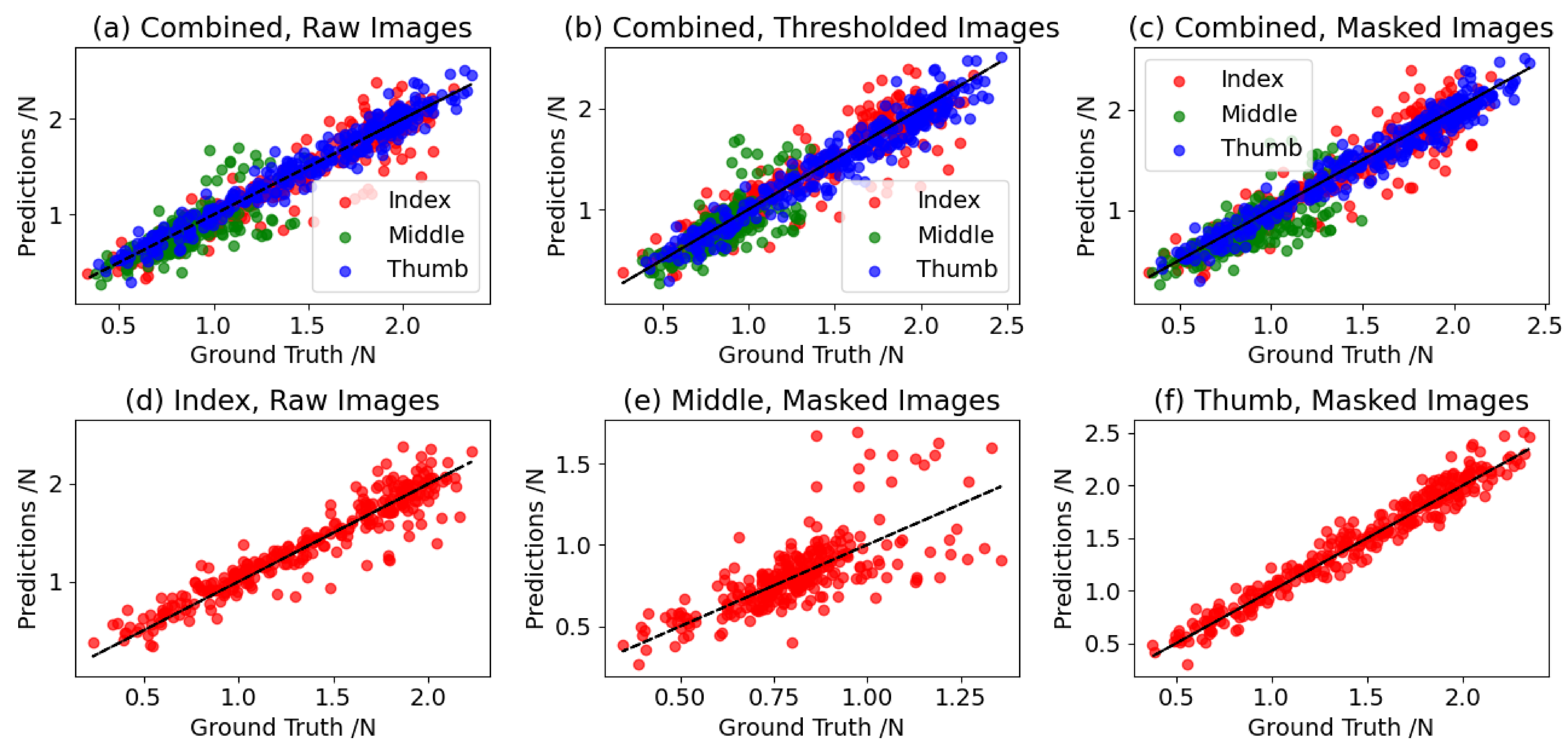
• Two modes of FF implemented: blocking (binary) feedback and variable FF (simulates stiffness of grasped object).
• Total cost of £92.91, 30−50 times less than commercial offerings.

[3] X. Hu, A. Wang, and A. Curtis, Remote feelings, 2021. https://github.com/BerkeleyCurtis/EECS249_HapticGlove, last accessed: 09-04-2023.

Contact Force Estimation



• A dataset of 3000 tactile images and corresponding force data is collected for each TacTip.
• A CNN is trained using the data for each sensor as well as a CNN using the data from all three sensors.
• Best trade-off between accuracy and inference time found with combined dataset which is recommended for use in teleoperation.
• Three tactile image processing methods are explored: no processing, Gaussian adaptive thresholding and masking the image with detected blobs.



• MAE of 0.1012N achieved with combined dataset. MAE of 0.1214N, 0.1069N and 0.0848N for index, middle and thumb sensors.

Teleoperation Framework

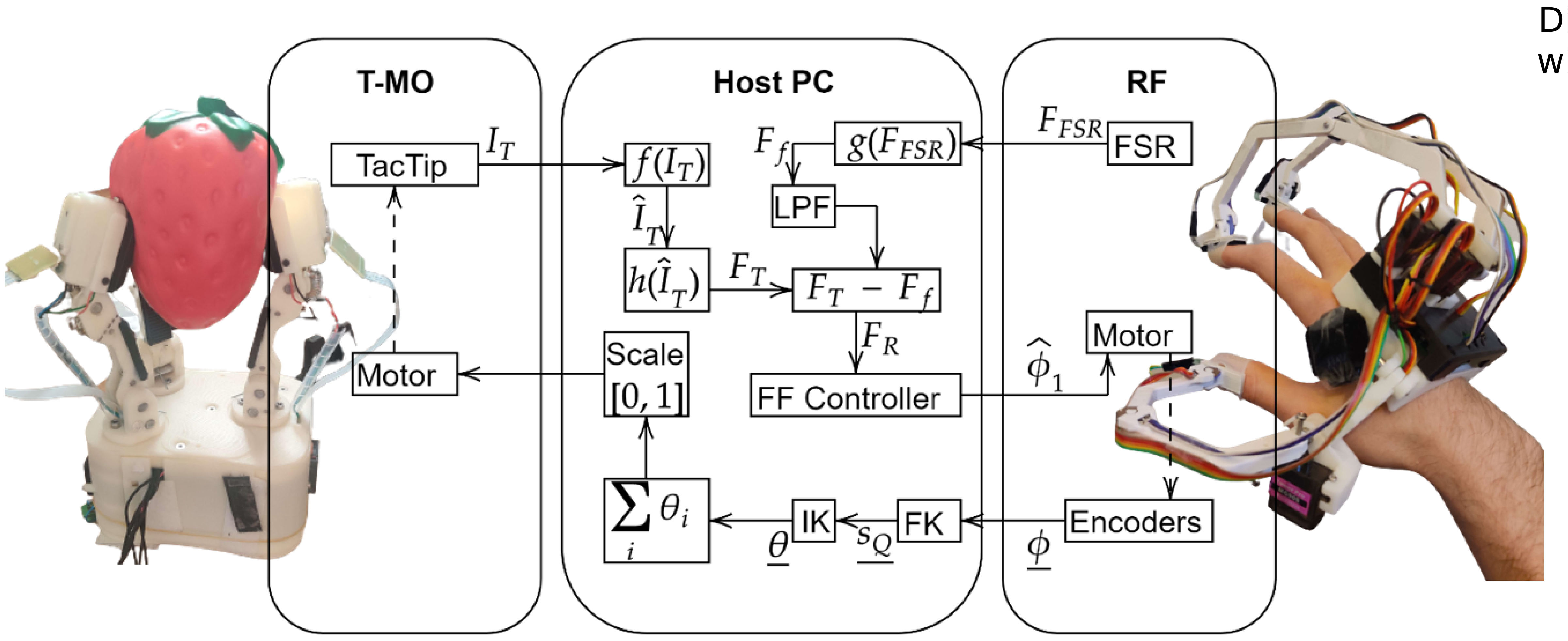
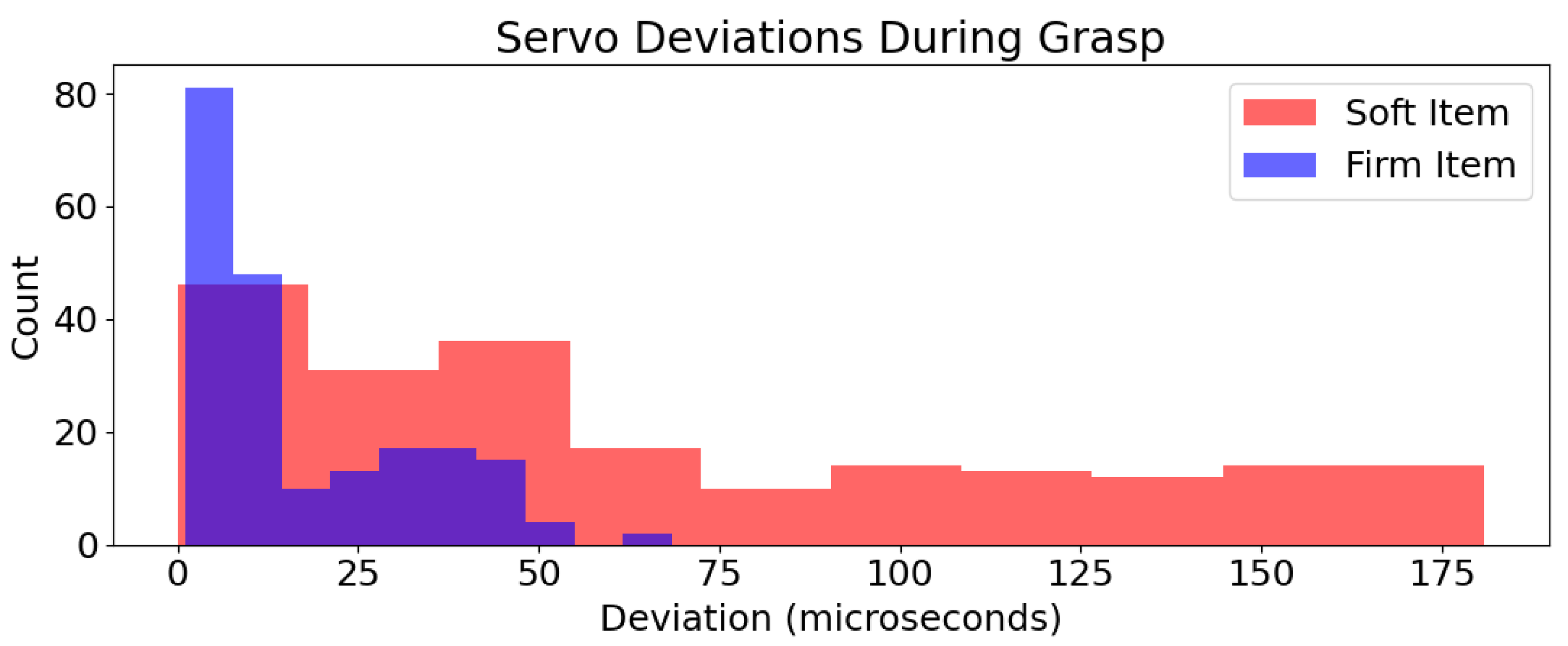


Diagram outlining the teleoperation procedure with RF and the T-MO.

- I_T denotes the tactile images and $\hat{I}_T$ denotes the processed images.
- F_T and F_f denote the forces on the TacTip and fingertip.
- f, g and h are functions for image processing, calculating the fingertip force and contact force estimation.
- $\underline{\phi}$ and $\underline{\theta}$ denote the exoskeleton and finger joint angles.
- FK and IK denote the forwards and inverse kinematics.
- $\hat{\phi}_1$ is the servo angle deviation required for providing FF.



Servo deviations from initial contact point recorded during grasps of a soft and a firm object, simulating varying stiffnesses.

Conclusion and Future Work

- Successfully kept costs low and accessibility high.
- RF and T-MO combination successfully allows rendering of variable stiffnesses.
- Contact force estimation accuracy stands to be improved.
- Room for addition of cutaneous feedback (e.g. via TactiGrip [3]).
- Further experimentation in impact of feedback on teleoperation tasks required.

[1] G. E. Barnaby, Breaking boundaries for adoption of accessible high fidelity haptic feedback technologies, PhD thesis, The University of Bristol, 2022.
[2] J. W. James, A. Church, L. Cramphorn, and N. F. Lepora, Tactile model o: Fabrication and testing of a 3d-printed, three-fingered tactile robot hand, Soft Robotics, 8 (2021), pp. 594–610.