Whole-Body Contact Sensing via Distributed Low-Cost Joint Torque Sensors For Legged Robots

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Introduction

- Legged robots need **contact awareness** beyond feet[1,2]
- Current methods use **friction models** or **sensor arrays**[3]
- **Brief** contacts during motion need **low-latency** sensing[4]

Momentum-Based Observer Framework

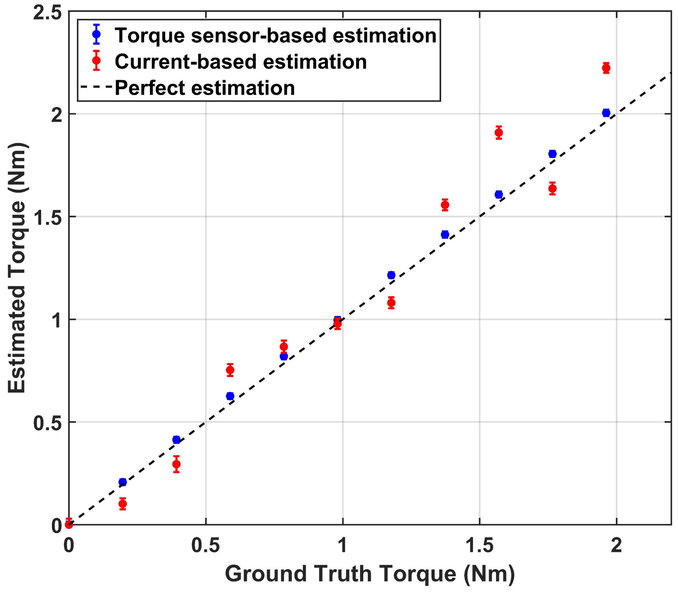
- Detect **gap** between expected and actual dynamics[3]
- Identify contacted link when **residual is nonzero**[3]

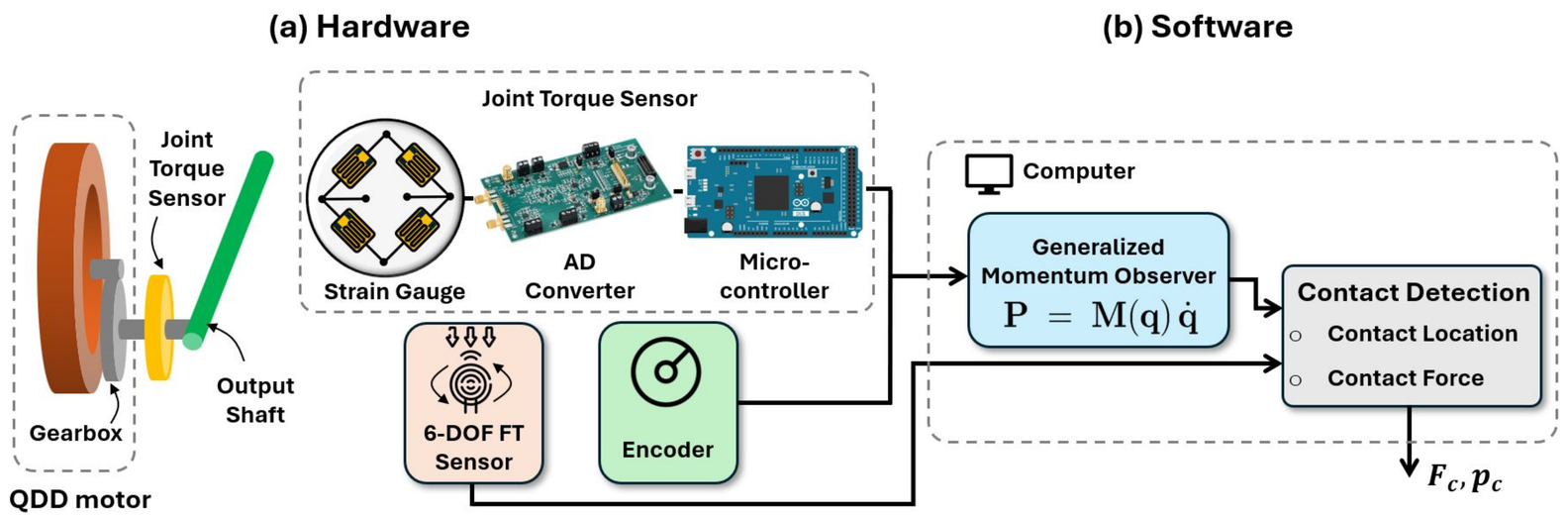
$$\mathbf{p}_{\text{int}}(t+\Delta t) \;=\; \mathbf{p}_{\text{int}}(t) \;+\; \Big[\mathbf{u} \;+\; \mathbf{r}(t)\Big]\Delta t.$$

- Traditionally torque estimates → **direct joint sensors**
- Zero-moment equation $\mathbf{p}_c \;=\; \mathbf{p}_1 \;+\; \alpha\,(\mathbf{p}_2 - \mathbf{p}_1), \quad \alpha \in [0,1]$ **finds contact point** along link $0 \;=\; M_y^{\text{unexp}} \;+\; \Big[p_c(1)\,F_z^{\text{unexp}} \;-\; p_c(2)\,F_x^{\text{unexp}}\Big]$

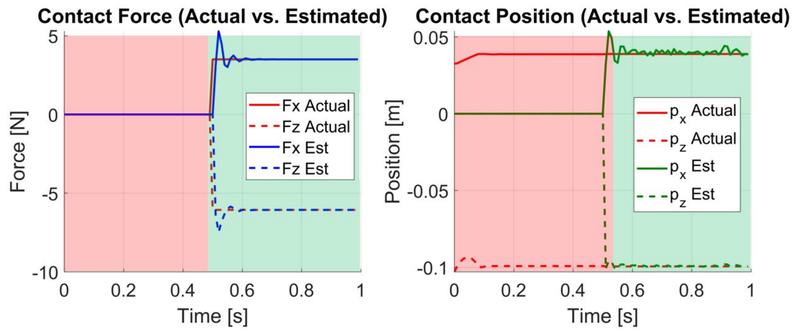
Sensor Performance

- **96.4% fidelity** to ground truth torque measurements
- **78.3% improvement** over motor-current estimation

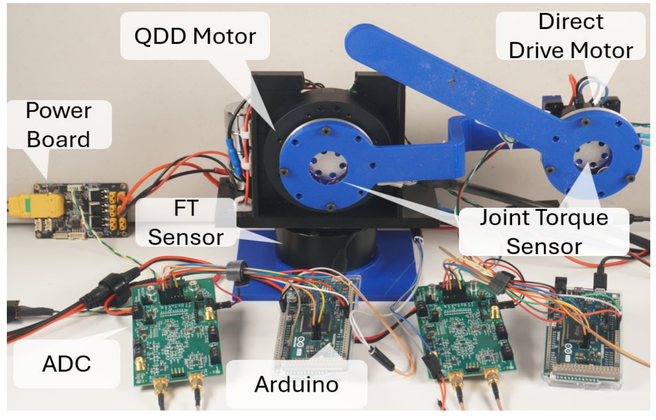




Results



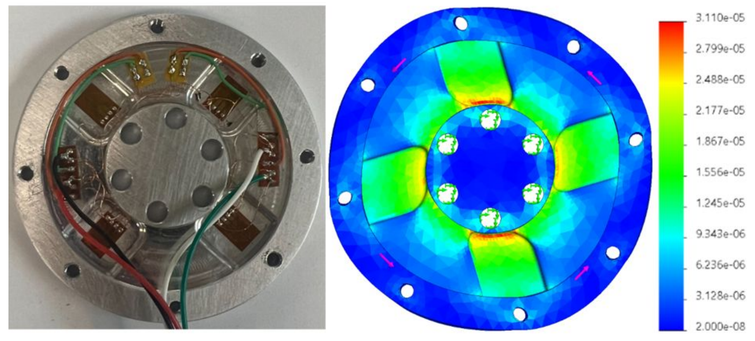
- **Simulation Above**
- **Hardware Setup Below**



All show sub-cm contact localization and <0.2N force error

Direct Joint Torque Sensor

- Full Wheatstone bridge strain gauges on output shaft
- **Range: 0–8.5Nm**
- **Resolution: 0.02Nm**



References

[1]Haddadin, S. et al. (2017). "Robot collisions: A survey on detection, isolation, and identification." IEEE Trans. Robotics, 33(6), 1292-1312.

[2]Iskandar, M. et al. (2024). "Intrinsic sense of touch for intuitive physical human-robot interaction." Science Robotics.

[3]De Luca, A. et al. (2005). "Sensorless collision detection and reaction for robot manipulators." Proc. IEEE Int. Conf. on Robotics and Automation (ICRA), 999-1004.

[4]Daley, M.A. et al. (2006). "Running over rough terrain reveals limb control for intrinsic stability." Proc. National Academy of Sciences, 103(42), 15681-15686.