Towards the Development of a Compact Tension Sensing Unit for Tendon Actuation Systems

Patrick Zheng[a], Kent K. Yamamoto[a,b], Y. Chitalia[b], P.J. Codd[a]
[a]Brain Tool Lab, Duke University, Durham, NC
[b]HeaRT Lab, University of Louisville, Louisville, KY

Tendon-actuated robots are promising for minimally invasive surgical applications due to their high dexterity, slim form factor, and actuation systems concentrated at the robot's base. However, tendon-driven actuation presents limitations, including difficulties in routing tendons, deviations from models due to friction, and challenges due to tendon elongation. Tendon elongation is particularly impactful, as the actuation mechanism's movement does not increase the tendon tension and, therefore, does not change the end-effector's position. To mitigate this, accurate tension measurements are essential for closed-loop control and reliable end-effector positioning.

This study presents a compact force-sensing design that aims to integrate real-time tension data into minimally invasive robotics platforms. Inspired by [1] and [2], the proposed sensor assembly consists of two components: a pushing unit containing a single pulley and a housing unit with two pulleys. The tendon is routed through the first housing pulley, passes through the pushing unit, and exits through the second housing pulley. As tension increases, the pushing unit is driven into the force sensor (FSS-SMT, Honeywell, Charlotte, NC, USA), which records the applied force. To further compact the design, linear guide bearings from [2] were removed, reducing the overall height. Low-friction polyethylene adhesive (Ultra-high Molecular Weight Polyethylene Tape, APT, Newmarket, Ontario, Canada) is applied at the contact points to smoothen the translation of the pushing unit into the housing. The final assembly has a length, width, and height of 22.00, 18.00, and 8.58 millimeters, respectively.

To assess measurement accuracy, the sensor assembly was tested using known weights (EISCO, Honeoye Falls, New York, USA) from 50 to 500 grams in 50-gram increments. Each weight was tested six times, and in between tests, the result was recorded, and the tendon was relaxed before reapplying the weight. For the first three trials, one end of the tendon was secured to a flat surface, while the other end passed through the sensor mechanism and around a pulley to suspend weights in mid-air. These three trials were used to determine the conversion between the microcontroller's analog output to newtons. For the next three trials, the tendon was detached from the flat surface and hooked onto a load cell (DFG35-2, Omega, Norwalk, Connecticut, USA).

Using the previously determined conversion, the force sensor readings were transformed into newtons and compared with the readings from the load cell. The resulting outputs are shown in Figure 1c. The RMSE between the load cell and tension sensing unit readings is 0.176 N, indicating that the compact tendon sensing unit provides similar measurements to a real load cell at a much cheaper cost and smaller form factor.

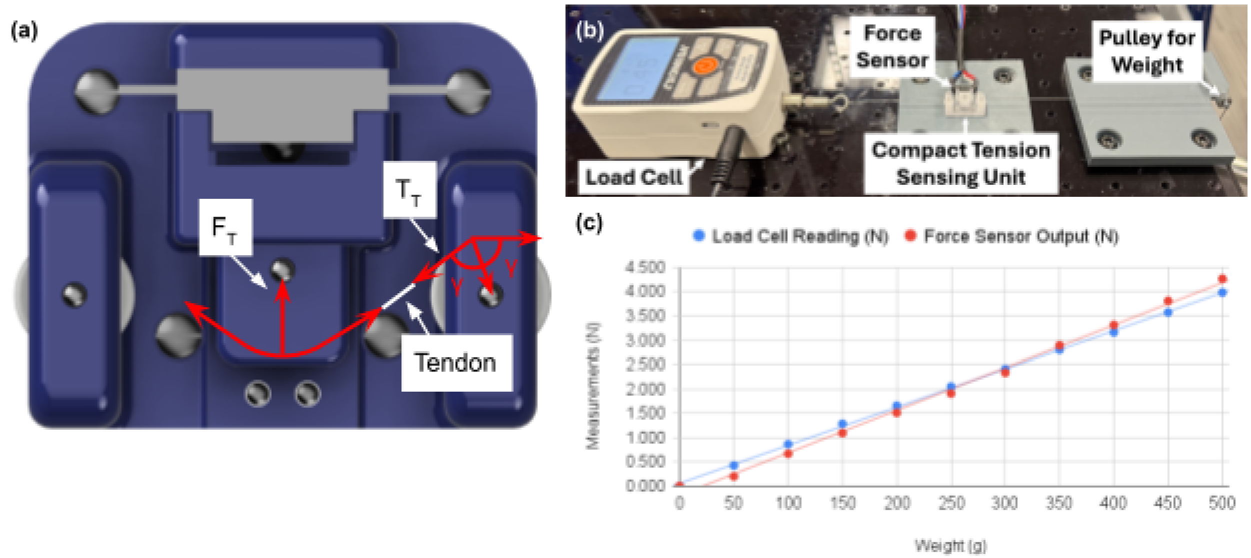

Fig. 1. (a) Compact Tension Sensing Unit CAD and diagram to calculate tendon tension in terms of measured force. (b) Experimental setup with load cell. (c) Graph indicating measured force in newtons from the load cell and the force sensor with respect to the applied weight in grams.

References:

[1] Tran P, Elliott D, Herrin K, Bhatia S, Desai JP. Evaluation of the FLEXotendon glove-III through a human subject case study. Biomed Eng Lett. 2023 Jan 27;13(2):153-163. doi: 10.1007/s13534-023-00262-2. PMID: 37124112; PMCID: PMC10130284.

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