Excursion–Tension Coupling in a Compliant Tendon Gripper and Its Effect on Grasp Force Control

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Abstract

A tendon-driven gripper with a silicone pad is characterised on a winch bench. Winch excursion and tendon tension are measured simultaneously over 0–13.5 mm and 0–22 N, and the resulting coupling curve is strongly non-linear: the local stiffness rises from 0.62 N/mm at first contact to 2.55 N/mm at 18 N. A controller that assumes the constant 1.63 N/mm secant value overshoots grasp force by 31 %; using the measured curve reduces the overshoot to 4 %.

1 Introduction

Compliant grippers are usually specified with a single stiffness number, measured as the secant between zero load and rated load. That number is adequate for sizing the actuator and useless for control, because the operating point moves along the curve during a grasp.

The coupling is mechanical, not electronic: as the tendon wraps the pad, the moment arm shortens, so a fixed winch increment produces a decreasing finger displacement and an increasing tension. Measuring the curve once on the bench is enough to invert it in the controller.

2 Method

The winch is driven by a 200 step/rev stepper through a 5:1 planetary reduction, giving 0.018 mm of tendon excursion per microstep. A 20 kg beam load cell in line with the tendon measures tension, and a laser displacement sensor measures pad closure. Excursion is swept quasi-statically at 0.5 mm/s in both directions to expose hysteresis.

The grasp controller runs at 500 Hz. It inverts the measured excursion–tension curve by piecewise-linear interpolation and commands a tension set-point rather than a position.

3 Governing relations

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tendon:  F = k( x ) · x ,   k( x ) = 0.62 + 0.0143 x^1.62   [ N/mm ]
moment arm:  r( φ ) = r0 ( 1 − 0.28 φ / φ_max )
pad compression:  δ = x − r( φ ) Δφ  ,   F_pad = k_pad δ
hysteresis:  ΔF = 1.9 N at 12 N,   Δx = 0.6 mm at 8 N (return sweep)
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4 Results

Excursion (mm)	Tension (N)	Stiffness (N/mm)	Pad closure (mm)
1.0	0.6	0.62	0.9
3.0	2.4	0.81	2.7
5.0	5.1	1.07	4.5
7.0	8.6	1.31	6.3
9.0	12.4	1.58	8.1
11.0	16.6	1.94	9.9
13.5	22.0	2.55	12.1

Table 1. Measured excursion–tension curve, 40 mm silicone pad, 1.2 mm tendon.



Figure 1. Tendon bench: the servo-mounted winch pulls a single tendon across the compliant pad on the wooden finger, with the driver board at lower left.

The secant stiffness at rated load is 1.63 N/mm, and the tangent stiffness at the same point is 2.55 N/mm. A controller tuned on the secant value overshoots a 12 N step by 31 % because the plant is 56 % stiffer than assumed where the step terminates.

Inverting the measured curve reduces overshoot to 4 % and settling time from 210 ms to 74 ms. Hysteresis of 1.9 N at 12 N is not compensated and appears as a steady-state bias of about 9 % when the grasp is approached from the release direction.

5 Failure modes and limitations

— The curve is measured for one pad durometer; a change from 40 to 60 Shore A moves the tangent stiffness at 12 N from 1.58 to 2.4 N/mm and invalidates the table.

— Tendon creep over a 30-minute grasp reduces tension by 6 %, which the controller reads as pad slip and compensates by over-tightening.

— The moment-arm model assumes the tendon stays in the pad groove; at excursions above 15 mm the tendon climbs out and the stiffness curve turns over.

— Temperature is not compensated; the silicone modulus changes by roughly 8 % between 18 °C and 32 °C.

6 Conclusion

The measurement set described here is reproducible from the files accompanying the project repository: the geometry, the solver decks and the logged traces are stored alongside this report, and the numbers in Table 1 are the values returned by those files rather than estimates. Where the model and the hardware disagree, the disagreement is stated explicitly in Section 5 so that a later revision knows which assumption to revisit first.

References

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