

SWITCHING CONTROL TO ACTUATE ELBOW MOTION

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INTRODUCTION

Injuries and trauma to the elbow can lead to difficulty with activities of daily living. Two particular clinical issues provide the impetus for developing a controlled elbow joint motion simulator (JMS) for cadaveric specimens. First, insertion of a radial head prosthesis may be necessary after an unreconstructable, comminuted radial head fracture and second, ulnar collateral ligament (UCL) injuries are common among athletes. To quantify effects after surgical intervention, it is useful to have a system that actuates the arm in a repeatable, physiologic manner. (Johnson *et al.*, 2000) We propose that a switching algorithm can successfully control both flexion-extension (F-E) with a constant pronation-supination (P-S) angle and P-S while maintaining a constant flexion angle.

METHODS

The JMS has four major components: the frame, controller, actuators, and sensors. The frame constrains the elbow, supports the motors and provides physiologic lines of action for the applied forces which simulate muscle tension. (Magnusen, 2002, Kuxhaus et al., 2005) Full controllability of the elbow's two degrees of freedom is available via the *brachialis* (flexion), *triceps* (extension), *biceps* (flexion, supination), and *pronator teres* (pronation). The controller, drives, and motors (ACR8020, Gemini GV, and BE Series, Parker Hannifin, Rohnert Park, CA) apply loads to replicate muscle

tension. Displacement feedback is provided by two potentiometers (P1401a, Novotechnik, Southborough, MA) powered by a DC power supply (HP6284A, Hewlett Packard, Palo Alto, CA). Force feedback is supplied by load cells (Model 31, Honeywell Sensotec, Columbus, OH) conditioned by strain gage conditioners (Model 3270, Daytronic, Dayton, OH). 80lb line connects tendons to the actuators (Super Braid, Stren, Spirit Lake, IA).

Two similar algorithms control motion based on a logical switching algorithm, both driven with discrete PI controllers. The first controls F-E for UCL testing. The arm's inertia combined with the unidirectional, cable actuation can cause slack in the agonist during high speed movements. Joint stability is compromised, propelling the load-controlled antagonist into a sudden movement to reestablish joint stiffness possibly causing travel overshoot problems. The first algorithm overcomes this instability at higher speeds by switching primary movers between the *brachialis* for flexion and *triceps* for extension.

The second algorithm controls P-S through the *biceps* and *pronator teres* as above while maintaining a fixed flexion angle. EMG measurement has shown that constant flexion angle is maintained by tapering the *brachialis* force while the *biceps*' activation increases. (Naito, 2004) This effect can be recreated with a JMS by modulating the *brachialis* according to the arm flexion angle. As the *biceps* apply tension for

supination, the added flexion moment is countered by sufficiently reducing *brachialis* tension. Due to the cable/tendon actuation, it is necessary to maintain a minimum load on the *brachialis* to prevent slack and ensure stability because no compressive load may be applied. If, in an effort to maintain flexion angle, the *brachialis* tension falls below a minimum load level, *triceps*' activation provides the equalizing moment.

The controller was validated on a mechanical elbow with physiologic dimensions and insertions. The mean error, standard deviation and system precision were used to determine the system's tracking abilities. The mean error and standard deviation measure accuracy with regard to the difference between the reference and actual position after removing the control system lag which is determined through a cross correlation computation. System precision is found from averaging the standard deviation of three trials at each sample point.

RESULTS AND DISCUSSION

Figures 1 and 2 show the tracking error and the force modulation. The system tracks a sinusoidal input (Fig. 1) at an average error of 0.44° (P-S) and 0.12° (F-E). The average deviations between the reference and actual position are 1.05° (P-S) and 0.81° (F-E). The precision is on average 1.40° (P-S) and 0.21° (F-E). Figure 2 shows the change in forces during supination. The accuracy and precision results indicate that the algorithms can successfully control both P-S and F-E.

SUMMARY

The switching control algorithm to actuate cadaveric elbow specimens is accurate and repeatable. Future work will include studies

of radial head prostheses, ligament strain measurement, and controller refinements.

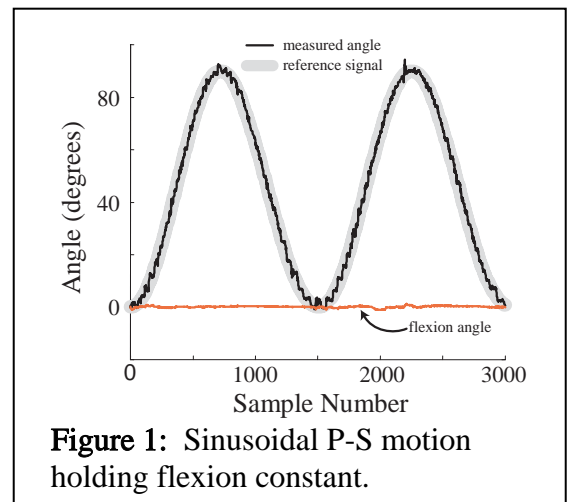


Figure 1: Sinusoidal P-S motion holding flexion constant.

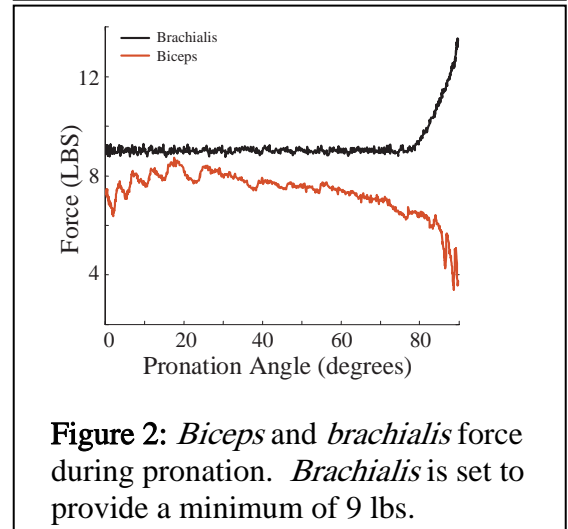


Figure 2: *Biceps* and *brachialis* force during pronation. *Brachialis* is set to provide a minimum of 9 lbs.

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