Calibration of Dynamic Hand-Wrist EMG-Force Models using a Minimum Number of Electrodes[†]

B. Bardizbanian[1], Z. Zhu[1], J. Li[1], C. Dai[2], C. Martinez-Luna[3], X Huang[1], T. Farrell[3],
E. A. Clancy[1]

1. Worcester Polytechnic Institute (WPI), Worcester, MA, USA
2. U. North Carolina-Chapel Hill, North Carolina State U., USA
3. Liberating Technologies, Inc., Holliston, MA, USA
{berj, zzhu2, jli6, xhuang, ted}@wpi.edu, cdai@email.unc.edu,
{carlos.martinez, todd.farrell}@liberatingtech.com

EMG-force models are used in many areas, including: prosthesis control [1, 2] (to command the direction and speed of movement), clinical biomechanics [3, 4] (to assess healthy muscle timing and effort levels), and ergonomics analysis [5, 6] (to assess risk of injury). Advanced EMG–force models incorporate subject-specific and task-specific dynamics, and are calibrated from contractions with time durations of upwards of 1–2 minutes. For various models, we studied EMG-force estimation error vs. calibration duration for two degree-of-freedom (2-DoF) hand-wrist contractions. We also studied the role of number of electrodes on EMG-force estimation error. Reducing the calibration duration and/or number of electrodes makes EMG-force modeling more accessible, by reducing task time and equipment cost.

Similar to [7, 8], 16 conventional bipolar electrodes were circumferentially mounted about the proximal forearm (nine subjects). The dominant hand was secured to a three-axis load cell to measure wrist extension-flexion (Ext-Flx), radial-ulnar deviation (Rad-Uln) and pronation-supination (Pro-Sup) forces/moment. The fingers of the same hand were secured to a second single-axis load cell to measure hand open-close (Opn-Cls) force. A PC produced 40 s duration uniform random (0.75 Hz, white, bandlimited) force targets on-screen either along one of these four contraction dimensions per trial (1-DoF), or as 2-DoF contractions comprised of the hand paired with one wrist dimension. Effort ranged over 0–30% maximum voluntary contraction (MVC). Separately for each subject, linear, FIR (20th order), and 2-DoF regression models related EMG standard deviation (EMGσ) to force using two 1-DoF and two 2-DoF training trials. Initially, all 16 electrodes and 76 s of data were inputs. Thereafter, the number of electrodes was sequentially reduced using a backward stepwise selection procedure on the training data. RMS error on two separate test trials was evaluated at each step. For each number of electrodes, training duration was also progressively decreased and tested. We repeated this complete analysis, instead using only one filter per DoF pair, ensemble-averaged across subjects, but gain-normalized for each subject. That is, only electrode gains were calibrated for each subject. Finally, a "universal" fixed dynamic model (ensemble-averaged across all subjects and DoFs) was compared. Again, only the gain of each electrode was calibrated.

Fig. 1 shows summary test error results for one of the three DoF pairs. Error results for the other DoF pairs were quite similar. Models using either one electrode or a 6 s calibration duration exhibited noticeably higher error, causing significant statistical interactions. Since these two parameter extremes represented unrealistic values, they were excluded from further analysis.
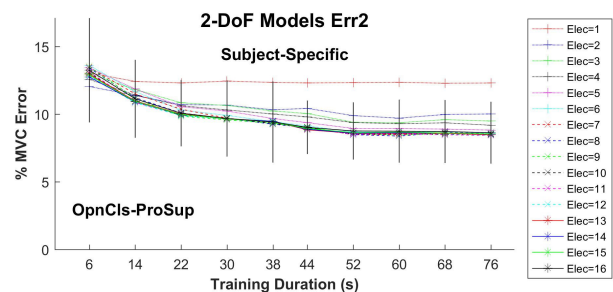

Fig. 1. Two-DoF summary error results: subject-specific models, Opn-Cls & Pro-Sup pair vs. training duration for each number of backward selected electrodes. Markers show means. Vertical lines show standard deviations only for 16-electrode models. Standard deviations for other numbers of electrodes were similar.

Using the remaining RMS error results, a three-way RANOVA was computed for each DoF pair (Factors: Model—subject-specific, one per DoF pair, universal; Electrodes—2–16; Training Duration—14, 22, 30, 38, 44, 52, 60, 68 and 76 s). All main effects were significant, without interactions (F>8.5, p<0.02).

Tukey *post hoc* comparisons first found a significant difference in RMS error between universal filtering, DoF-specific filtering and subject-specific filtering. The simpler universal filtering had lower mean error. Second, there was no significant RMS error difference for durations of ≥44 s for Opn-Cls with Flx-Ext, ≥52 s for Opn-Cls with Rad-Uln, and ≥60 s for Opn-Cls with Pro-Sup. Finally, RMS error using ≥7 electrodes was not significantly different for Opn-Cls with Flx-Ext, ≥8 electrodes for Opn-Cls with Pro-Sup, and ≥10 electrodes for Opn-Cls with Rad-Uln. Future work in this area should recognize that these statistical differences need to be weighted vs. their clinical significance/strength in a given application.

REFERENCES

[1]   R. W. Mann and S. D. Reimers, "Kinesthetic sensing for the EMG controlled "Boston Arm"," *IEEE Trans. Man-Mach. Sys.,* vol. 11, no. 1, pp. 110–115, 1970.

[2]   P. Parker, K. Englehart, and B. Hudgins, "Myoelectric signal processing for control of powered limb prostheses," *J. Electromyo. Kinesiol.,* vol. 16, pp. 541–548, 2006.

[3]   C. A. M. Doorenbosch and J. Harlaar, "A clinically applicable EMG-force model to quantify active stabilization of the knee after a lesion of the anterior cruciate ligament," *Clin. Biomech.,* vol. 18, pp. 142–149, 2003.

[4]   C. Disselhorst-Klug, T. Schmitz-Rode, and G. Rau, "Surface electromyography and muscle force: Limits in sEMG-force relationship and new approaches for applications," *Clin. Biomech.,* vol. 24, pp. 225–235, 2009.

[5]   S. Kumar and A. Mital, *Electromyography in Ergonomics*. Briston, PA: Taylor & Francis, 1996.

[6]   G. M. Hagg, B. Melin, and R. Kadefors, "Applications in ergonomics," in *Electromyography: Physiology, Engineering, and Noninvasive Applications*, R. Merletti and P. A. Parker, Eds.: IEEE Press/Wiley-Interscience, 2004, pp. 343–363.

[7]   E. A. Clancy, C. Martinez-Luna, M. Wartenberg, C. Dai, and T. Farrell, "Two degrees of freedom quasi-static EMG-force at the wrist using a minimum number of electrodes," *J Electromyogr Kinesiol,* vol. 34, pp. 24–36, 2017.

[8]   Z. Zhu, M. Wartenberg, E. A. Clancy, C. Martinez-Luna, and T. Farrell, "A pilot study of two degrees of freedom dynamic EMG-force at the wrist using a minimum number of electrodes," in *IEEE Sig. Proc. Med. Biol. Sym.*, Philadelphia, PA, 2017.