Artificial Neural Network Prediction of Center of Pressure Using Trunk Acceleration Inputs During Perturbed Human Bipedal Stance

[1]Raviraj Nataraj, [1,2]Ronald J. Triolo, [1,2]Robert F. Kirsch, [1,2]Musa L. Audu, [2]Rudi Kobetic
[1]Case Western Reserve University,
[2]Louis Stokes Veteran's Administration Medical Center; e-mail: rxn25@po.cwru.edu

INTRODUCTION

This study investigates the feasibility of artificial neural network (ANN) prediction of changes in center of pressure (COP) during perturbed human bipedal stance using current and past COP and trunk acceleration inputs. The COP – COM (center of mass) variable has been shown to be correlated to COM acceleration during quiet standing [1]. We hypothesize that accelerations of a point on the trunk (estimate of COM) can be implemented by an ANN to predict COP. We seek to employ this ANN in a dynamic, feed-forward manner for controlling standing posture using functional neuromuscular stimulation (FNS) following spinal cord injury (SCI). Due to the delay in peak muscle force production after initial stimulation, we will apply a control loop that acts predictively by minimizing the difference between a desired COP and a *future* COP determined by the ANN.

METHODS

Two able-bodied male subjects (25-27 yrs) have participated thus far. Each subject wore two belts, one around the waist and one around the chest (figure 1). Both belts were fastened to four non-elastic cotton-cloth ropes. Each rope was aligned in either the anterior-posterior (A-P) or medial-lateral (M-L) directions relative to the subject. Ropes were used to manually apply perturbations to the subject standing on an instrumented force-plate that actively measured COP. The subject wore a retroreflective sternum marker whose 3-D position was tracked using a VICON© camera system. The position data were double-differentiated off-line using a derivative-filter [2] to obtain trunk accelerations. Trials consisted of perturbing the subject, initially in erect stance, in different combinations of rope-pulls. Perturbations were moderate such that significant COP deviations were incurred yet the subject could make postural corrections to maintain bipedal stance without stepping.

Data from the aforementioned trials were used for training and testing an ANN for COP prediction at several future time increments (100, 150, 200, 250, 300 msec) on the order of neuromuscular delay. A three-layer, time-delayed feed-forward network [3] for back-propagation training was created. The inputs into the network were current and past values of three orthogonal acceleration components (x, y, z) and two horizontal-plane COP components (A-P, M-L). The outputs were changes in the two COP components at the previously specified future time-instants.

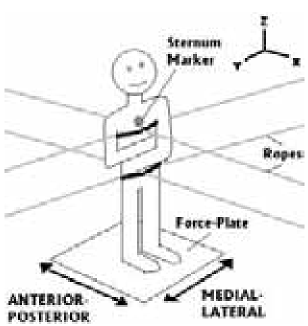

Figure 1. Experimental Set-up (not to scale)

RESULTS AND DISCUSSION

After ANN training, correlation coefficients (R^2) between true COP change and ANN-predicted output for test data were calculated as a measure of their respective fit. Results from a test sample having both A-P and M-L perturbations are shown in figure 2. Substantial correlation (> 0.7) exists for both the A-P and M-L components.

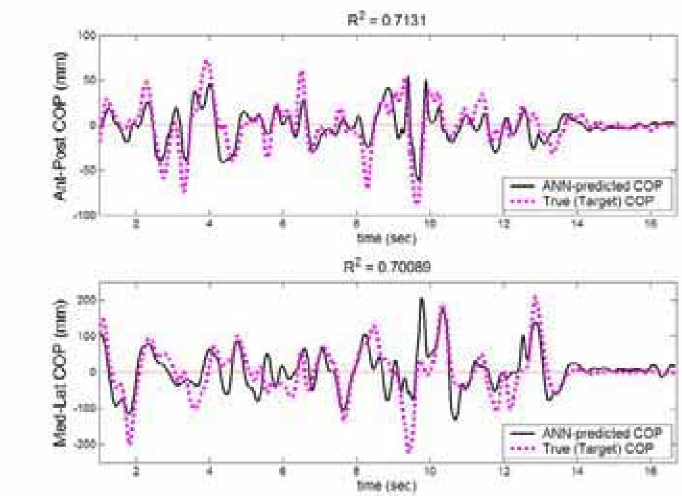

Figure 2. ANN prediction (200 msec in future) of changes in Ant-Post (top) and Med-Lat (bottom) COP for 1000-point (60 Hz sampling rate → 16.7 sec) test sample.

Improved correlation is expected with additional inputs (more markers, additional past values) and a more dynamic neural network structure that includes recurrent connections. Future investigations will implement accelerometer outputs rather than numeric differentiation of VICON position data. Accelerometer readings are likely not as accurate as the numerically-derived values currently used. However, it is expected that the accelerometer will be more sensitive to larger deviations in posture relative to steady-state swaying, making correlations during a perturbation trial higher. While feasibility has been demonstrated, the required accuracy of the ANN predictor can only be assessed when integrated in the full FNS control system. This will be done first in simulation prior to experimental evaluation.

REFERENCES

1. Winter DA, et al. *J Neurophysiol* **80**, 1211-2, 1998.
2. Kaiser JF, Reed WA. *Rev. Sci. Instrum* **48**, 1447-1455, 1977.
3. Lan N, Feng H-Q, Crago PE. *IEEE Trans Rehab Eng* **2**, 213-223, 1994.

ACKNOWLEDGEMENTS

NIH: R01NS040547-03 Research Project Grant
NIH: 9T32EB04314-06 Training Grant