Estimating Center of Mass Kinematics during Human Walking using Accelerometers

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I. Introduction

Lower-limb paralysis caused by spinal cord injuries (SCIs) can limit mobility, social interactions, and prohibit a healthy lifestyle [1]. Powered exoskeletons are an emerging trend for restoring mobility for individuals with an SCI. However, current commercialized exoskeletons are unable to provide balance correction, which forces users to resist destabilizing movements by bracing onto crutches or a walker. These balance corrections lead to an increased metabolic cost with walking speeds too slow for community use [2]. Improving the exoskeleton's practical usefulness requires controllers capable of resisting perturbations, thereby allowing for increased walking speed. In bipedal humanoid robots, many balancing control strategies use a global, whole-body balance parameter, like center of mass (COM) kinematics, to determine the instances and degree of instability [3]. In this study we propose a method to estimate the kinematics of the COM from acceleration signals measured by IMUs. The method could be easily implemented in exoskeletons used by individuals with SCI to enhance walking stability by controllers using the COM kinematics as feedback signals.

II. Methods

A. Data Collection

We collected data from one able-bodied subject walking within the work volume of a 16-camera motion capture system (Vicon, Oxford Metrics, UK). We placed 30 retroreflective markers on the participant and 8 tri-axial IMUs (Xsens Technologies, BV, Enschede, Netherlands) fixed in pairs on the right and left chest, pelvis, upper thighs, and lower thighs. The participant walked in 33 separate trials of walking back and forth across a 10-m long walkway. A "gold-standard" COM position was estimated from the motion inferred by the motion-capture along with regression equations of the US Army anthropometric studies.

B. COM Position Estimation Algorithm

The COM position Estimation algorithm is designed as a single-layer artificial neural network (ANN), where the inputs are the acceleration signals measured by the IMUs and the outputs are estimated COM position. The ANN has a single hidden layer of 40 neurons with sigmoidal transfer functions and linear functions in the output layer. We used the Deep Learning Toolbox™ in MATLAB and the Levenberg-Marquardt algorithm to train the ANN, where we serially specified 85% of the data for training and 15% for validation. The COM position from motion capture was used as output for network training. The ANN's performance was quantified using the mean-squared-error (MSE) between the COM measured experimentally and the COM predicted from the ANN.

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III. Preliminary Results

Figure 1 compares the COM measured experimentally (blue) and the COM predicted by the algorithm (orange) from the validation data. The root-mean-square error (RMSE) is 1.33 cm, with the largest errors occurring in the anterior-posterior direction of the COM. The coefficient of determination R^2 is 0.6, which suggests the performance follows the variation within the COM. Further training with more data is expected to improve this greatly.

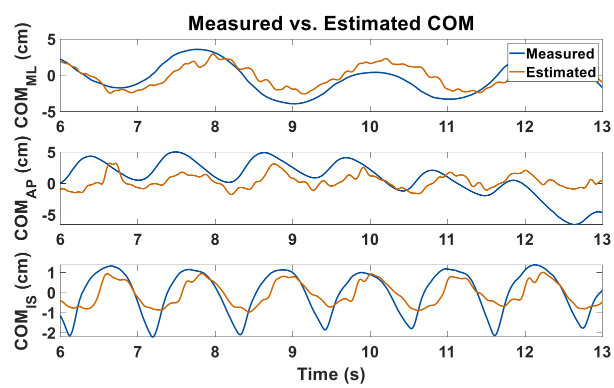

Figure 1. Center of mass (COM) displacements measured experimentally from motion capture (blue) and estimated through the COM Estimation Algorithm (orange) during a walking trial.

IV. Conclusion

Our initial findings suggest that the COM Estimation Algorithm can predict the majority of COM movements during walking at normal walking speed. Upcoming studies include collecting more able-bodied walking data to provide a richer data set for training the network.

References

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