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Estimating Center of Mass Kinematics during Perturbed Human Standing using Accelerometers

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Motivation and Objectives

Motivation

- Commercialized powered exoskeletons (**Fig. 1a**) are an emerging trend to restore mobility for individuals with spinal cord injuries
  - *-can only follow pre-defined motions*
  - *-unable to correct for postural instabilities [1]*
- Control systems are necessary to ensure balance during standing and walking with exoskeletons
- Center of mass (COM) position is an indicator of standing stability – See **Fig. 1b**. COM kinematics are typically used as feedback parameters for balance controllers [2]
- COM must be estimated in real-time using devices suitable for integrating into our hybrid exoskeleton

Fig. 1a

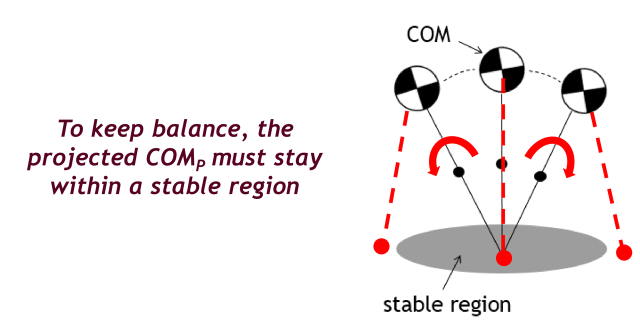


Fig. 1b

Objectives

1. *Design an experimental protocol, using internal and external perturbations, that causes measurable changes in a subject's center of mass position (COM_P)*
2. *Develop a COM Estimation Algorithm that predicts COM_P using accelerometers*

Able-Bodied Destabilization Experiments

Experimental Setup

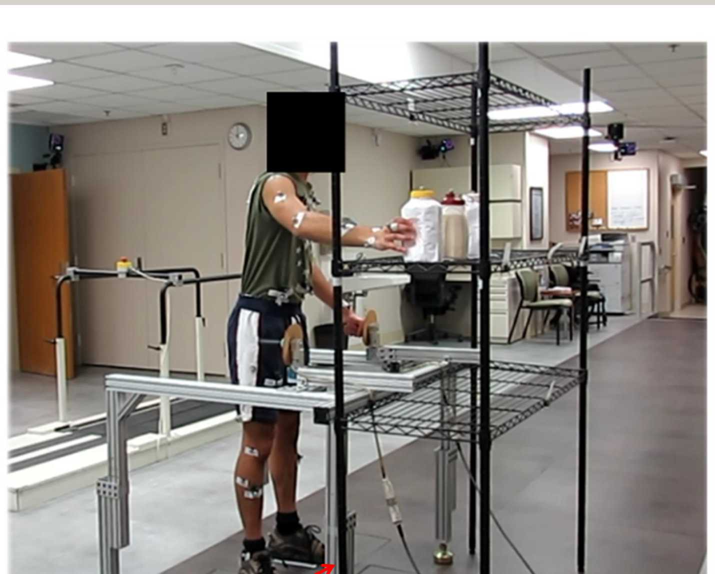
- 5 able-bodied experiments performed in our Motion Study Laboratory (MSL)
- 16 motion capture cameras estimated the participants' COM_P using 48 reflective markers (Vicon, Oxford Metrics, UK)
  - *-used to **measure** COM_P as the "gold-standard"*
- 10 accelerometers measure changes in acceleration (Delsys Trigno)
  - *-used to **estimate** COM_P through the algorithm*

External Perturbations

- Linear actuators pull participant in 4 directions: (Copley Motion Control, Canton, MA) *front (0), right (1), back (2), left (3)*
- 3 pull magnitudes: *small (S), medium (M), large (L)*
- MATLAB code randomly generates pull order and perturbation magnitude *(10 trials, 24 pulls each)*

4 Linear Actuators **2 Force Plates**

Internal Perturbations

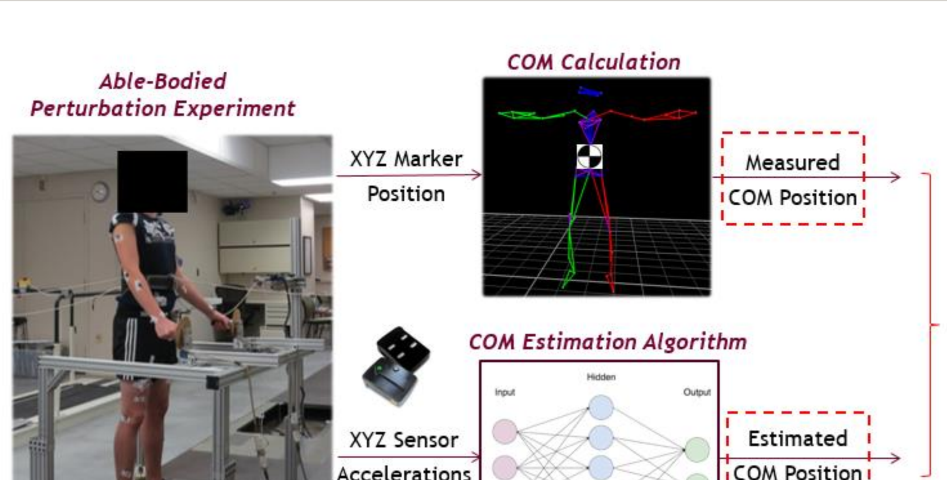


2 Force Plates **3 Loaded Jars**

- Participants move a weighted jar to 4 target locations: *up (1), left (2), right (3), bottom (4)*
- 3 different weights: *Heavy (A), Medium (B), Light (C)*
- MATLAB code randomly generates direction and jar weight *(10 trials, 30 perturbations each)*

COM Estimation Algorithm

- Artificial neural network
- **Inputs:** 30 accelerometer signals (10 sensors x 3 axes)
- **Outputs:** 2 COM_P signals (AP, ML directions)



Results

COM Displacements Induced by the Perturbations

Averaged projected COM_P from 5 participants (4 male, 1 female; median age = 23; median height = 1.71 m, median weight = 61.7 kg) are shown in **Fig. 2**.

- COM_P moved primarily **mediolateral (ML)** during **internal perturbations**
- COM_P moved primarily **anteriorposterior (AP)** during **external perturbations**

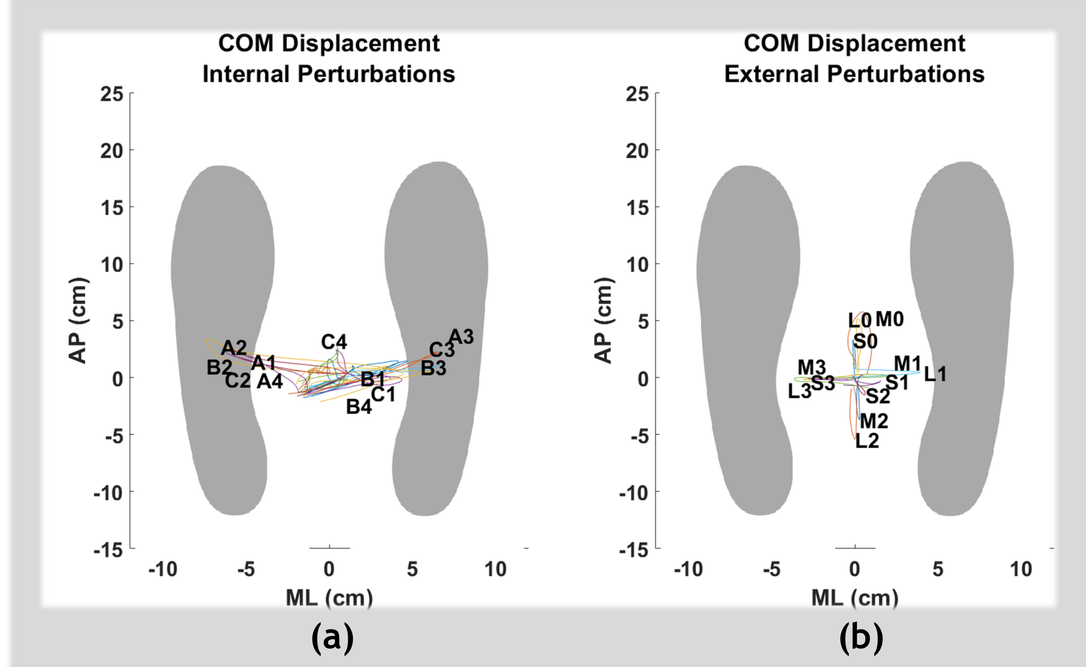


Fig 2. The projection of the subject's COMP measured experimentally using motion capture during **(a) the** internal perturbations and **(b)** the external perturbation trials.

COM Estimation Algorithm Performance

- Each perturbation type averaged across all participants
- Performance was quantified by calculating the **Root Mean Square Error (RMSE)** and the **Coefficient of Determination (R^2)** between the measured and predicted COM_P for each movement type (**Fig. 3**)
- A successful algorithm will achieve high R^2(>0.7) and a low RMSE error

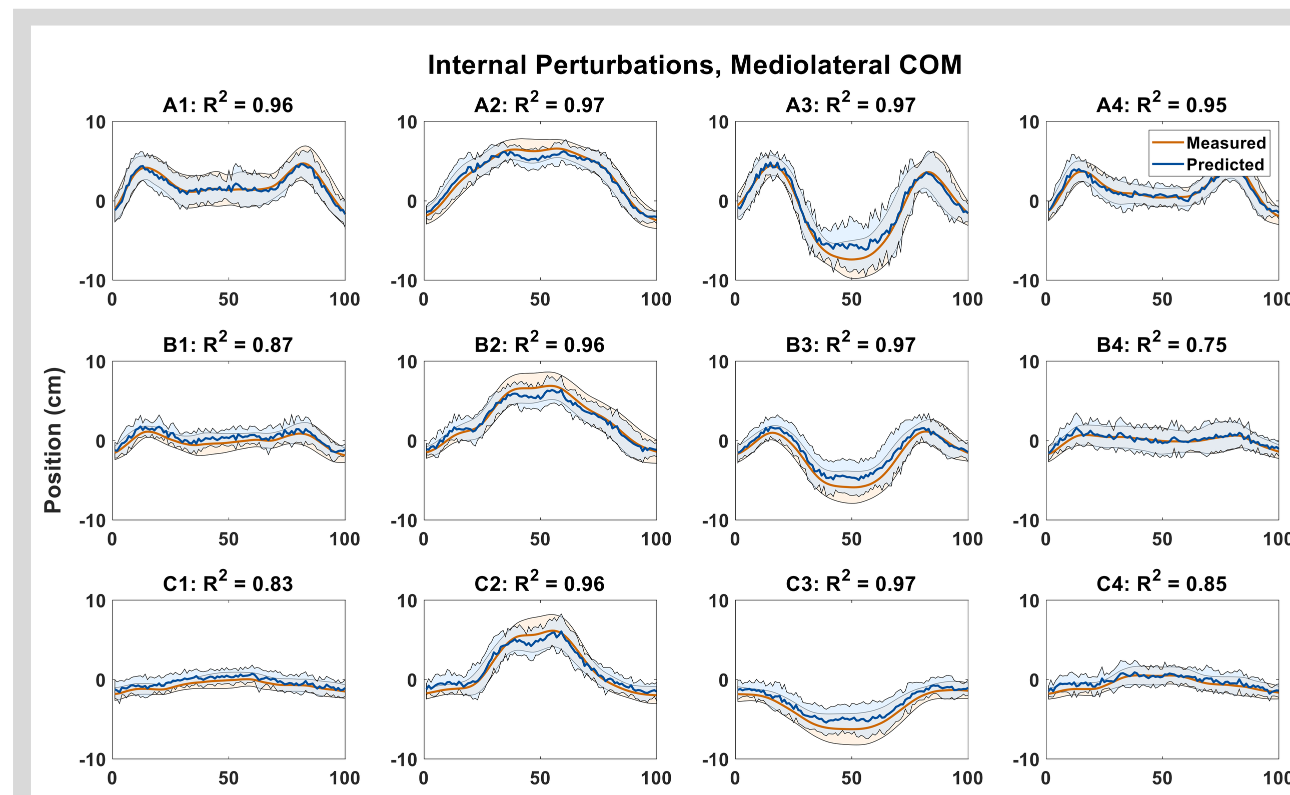


Fig 3. Representative results with measured (orange) and predicted (blue) COM in the mediolateral direction for the internal perturbations, averaged across all participants. The R^2 for the particular movement is shown at the top of each plot. Shaded regions correspond to one standard deviation

- In 90% of the perturbation types, the algorithm achieved an R^2 > 0.7, suggesting **the measured and predicted COM are highly correlated**
- Across all trials and subjects, the RMSE is 7.3% in the ML and 22% in AP, which is **less than 0.5 cm and 1.0 cm error**, respectively

Conclusion and Future Work

Completed Objectives

- The prescribed perturbations cause measurable changes in COM_P in response to the magnitude and direction
- The COM Estimation Algorithm can predict most COM changes in the sagittal and coronal planes, with errors in an acceptable range for use as a balance feedback term for our exoskeleton

Future Work

- Expand the protocol to include able-bodied walking
- Devise a procedure to better estimate COM changes in the IS direction

References

1. R. J. Farris, et al. *IEEE Trans. on Neural Syst. And Rehab. Eng.*, 2014, 22(3):482-490.
2. J. Y. Kim et. Al. *Advanced Robotics*, 2006, 20(6):707-736.

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