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

Objectives
1. Design an experimental protocol, using internal and external perturbations, that causes measurable changes in a subject’s center of mass position (COMx)
2. Develop a COM Estimation Algorithm that predicts COMx 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’ COMx using 48 reflective markers (Vicon, Oxford Metrics, UK)
- used to measure COMx as the “gold-standard”
- 10 accelerometers measure changes in acceleration (Varus, Tripsa)
- used to estimate COMx through the algorithm

External Perturbations
- Linear actuators pull participant in 4 directions: (Canopy 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)

Internal Perturbations
- 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 COMx signals (AP, ML directions)

Results

COM Displacements Induced by the Perturbations
Averaged projected COMx 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.
- COMx moved primarily mediolateral (ML) during internal perturbations
- COMx moved primarily anteriorposterior (AP) during external perturbations

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 (R2) between the measured and predicted COMx for each movement type (Fig. 3)
- A successful algorithm will achieve high R(>0.7) and a low RMSE error

In 90% of the perturbation types, the algorithm achieved an R2 > 0.7, suggesting the measured and predicted COMx 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 COMx in response to the magnitude and direction
- The COM Estimation Algorithm can predict most COMx 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 COMx changes in the IS direction

References

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