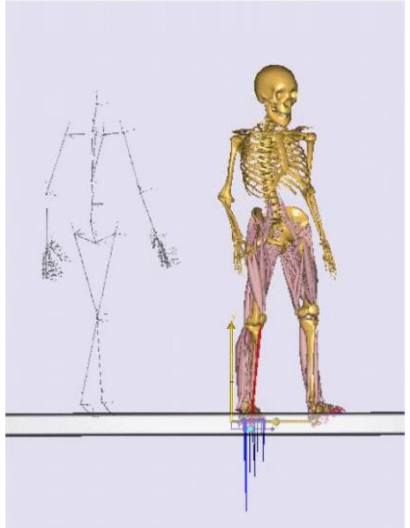
The webcast will start in a few minutes….

ANYBODY TECHNOLOGY



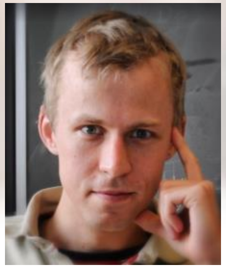
# Prediction of Kinetic Variables during Parkinsonian Gait

USING DEPTH SENSOR-DRIVEN MUSCULOSKELETAL MODELING

# Outline

- General introduction to the modeling system
- Presentation by Moataz Eltoukhy
  - Prediction of Kinetic Variables during Parkinsonian Gait
- Questions and answers


**Presenter:**
Moataz Eltoukhy, Ph.D.
Associate Professor,
Department of Kinesiology and Sport Sciences
Department of Industrial Engineering
University of Miami

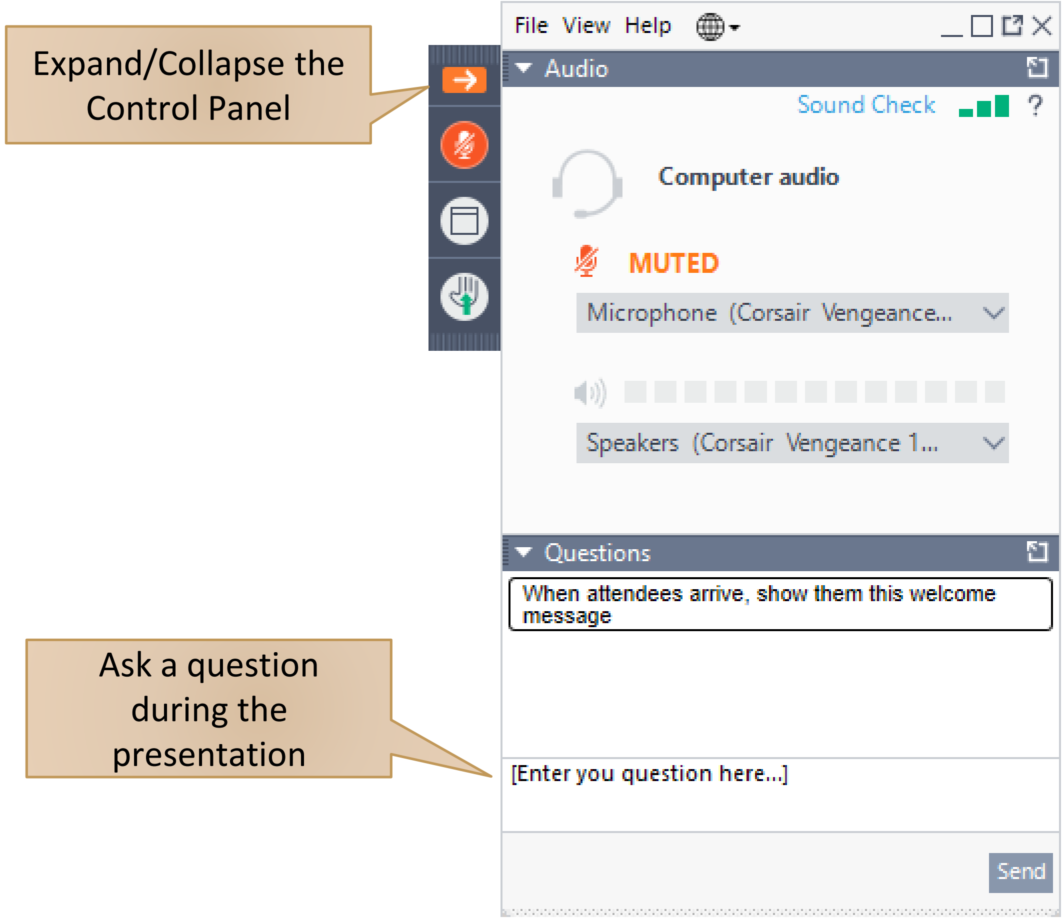

**Host:**
Morten Enemark Lund
Sr. R&D Engineer

# Control Panel

The Control Panel appears on the right side of your screen.

Submit questions and comments via the Questions panel.

*Questions will be addressed at the end of the presentation. If your question is not addressed we will do so by email.*



ANYBODY TECHNOLOGY

# Musculoskeletal Simulation

**Motion data**

Kinematics + Forces

→

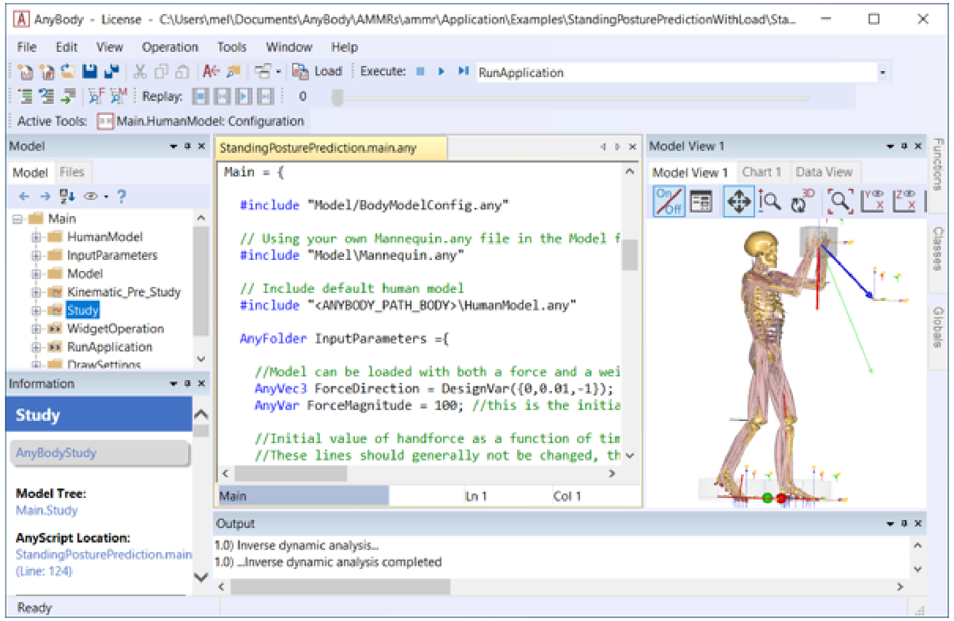
ANYBODY

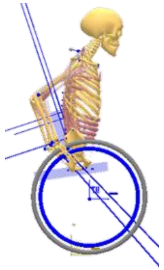
Modeling System

→

## Body Loads

- Joint moments
- Muscle forces
- Joint reaction forces



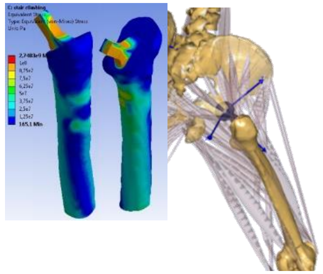


Product Design Optimization

Movement Analysis

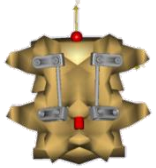
ANYBODY
Modeling System

Ergonomic Analysis



Load Cases for Finite Element Analysis

Surgical Planning and Outcome Evaluation

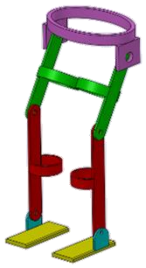


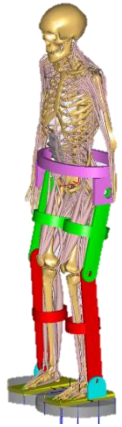
# AnyBody Modeling System

Motion data

Body model

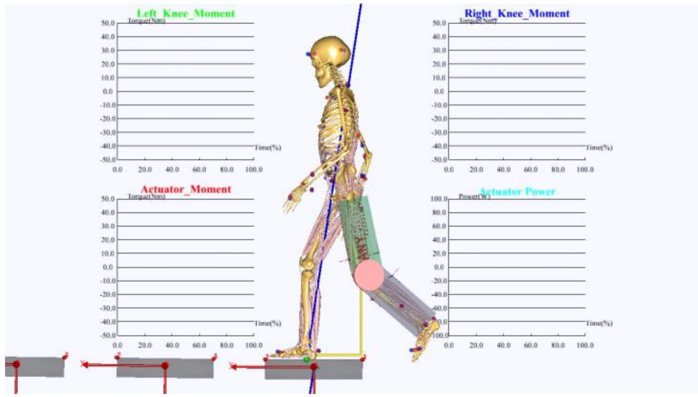
Environment model





Inverse dynamics
Muscle recruitment

Simulation




Internal body loads
- Muscle forces
- Joint forces

Design Optimization

Post Processing (e.g. FE tools)

UNIVERSITY OF MIAMI
SCHOOL of EDUCATION
& HUMAN DEVELOPMENT

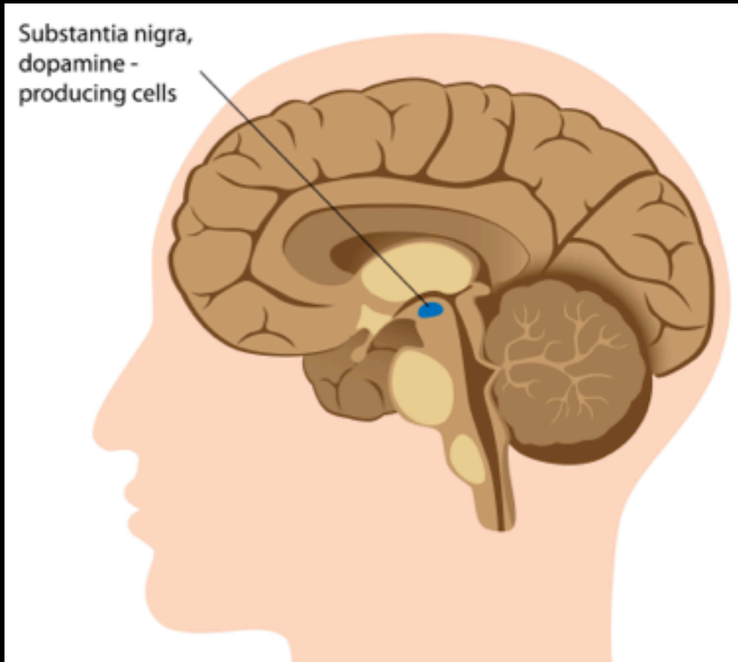
# Prediction of Kinetic Variables during Parkinsonian Gait using Depth Sensor-driven Musculoskeletal Modeling

Moataz Eltoukhy, PhD

# INTRODUCTION

# Parkinson’s Disease

- **Parkinson's disease** (**PD**) is a long-term degenerative disorder of the central nervous system that mainly affects the motor system.
- The motor symptoms of the disease result from the death of cells in the *substantia nigra*, a region of the midbrain.
- This results in not enough dopamine in this region of the brain.
  - Dopamine is a chemical that sends signals that control movement.

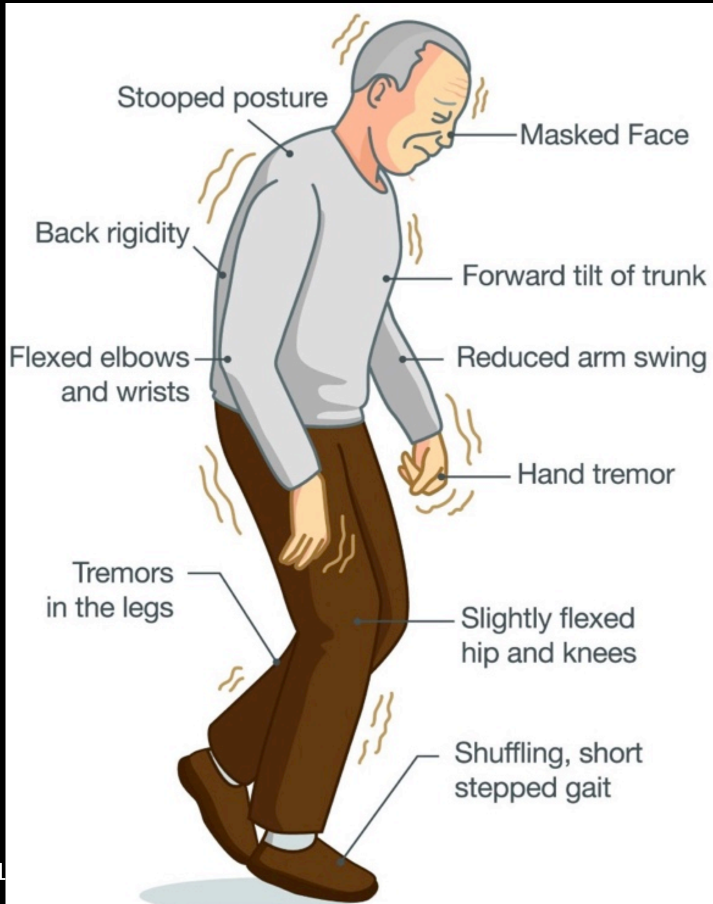


# Parkinson's Disease

- More than 10 million people worldwide are living with PD. Approximately 60,000 Americans are diagnosed with PD each year. Nearly one million will be living with PD in the U.S. by 2020.
- The combined direct and indirect cost of Parkinson's, including treatment, social security payments and lost income, is estimated to be nearly $52 billion per year in the United States alone.

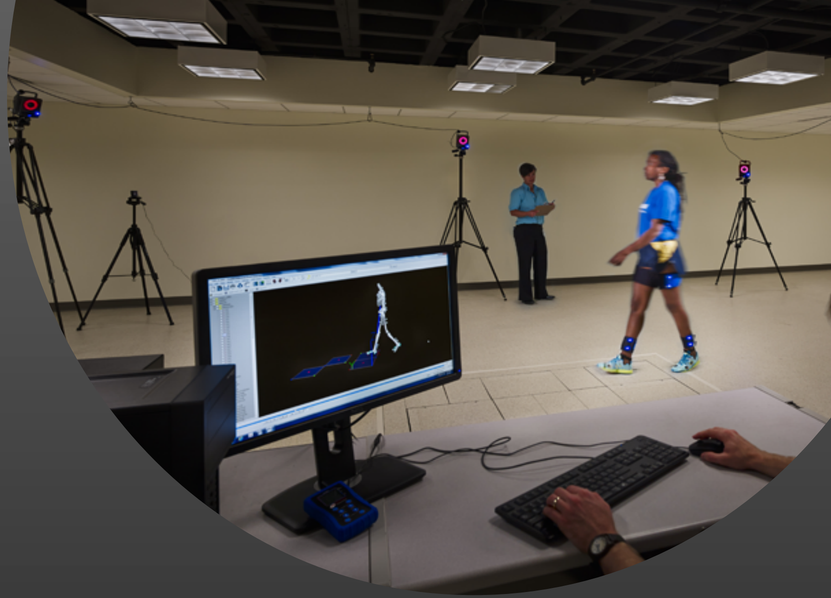
# Gait Assessment in Parkinson’s Disease Patients

- The most common characteristics of motor impairment among these individuals include:
  - Tremor, rigidity, impaired balance, shuffling short steps
  - Freezing of gait (FoG) [1,2] phenomenon, which is described by patients as have a feeling of their feet stuck to the ground and being temporally unable to initiate gait
- There are typical patterns of progression in PD that are defined in five stages.




[1] Backer, J.H. The symptom experience of patients with parkinson’s disease. J. Neurosci. Nurs. 2006, 38, 51–57.
[2] Nutt, J.G.; Bloem, B.R.; Giladi, N.; Hallett, M.; Horak, F.B.; Nieuwboer, A. Freezing of gait: Moving forward on a mysterious clinical phenomenon. Lancet Neurol. 2011, 1

# Gait Assessment in Parkinson's Disease Patients



- Clinicians usually use subjective scoring tools for gait assessment of their PD patients[1]
  - Self-report / Patient Diaries and Unified Parkinson Disease Rating Scale (UPDRS-III)
- While this has clinical benefit, it remains difficult to quantify the progress of disease or improvements due to clinical interventions. As well as the inability to include any kinetic outcome measures in this style of assessment.
- 3D motion capture (MoCap) systems can provide quantitative assessment of gait, including both kinematics and kinetics parameters commonly needed in clinical evaluations[2,3]

[1] Parkinson Study Group. (2001). Evaluation of dyskinesias in a pilot, randomized, placebo-controlled trial of remacemide in advanced Parkinson disease. Archives of neurology, 58(10), 1660..
[2] Muro-De-La-Herran, A., Garcia-Zapirain, B., & Mendez-Zorrilla, A. (2014). Gait analysis methods: An overview of wearable and non-wearable systems, highlighting clinical applications. Sensors, 14(2), 3362-3394.
[3] Vlasic, D. et al. (2007). Practical motion capture in everyday surroundings. In ACM transactions on graphics (TOG) (Vol. 26, No. 3, p. 35). Acm.

# Marker-based 3D MoCap Systems

- Despite being considered the gold standard technique[1,2] able to provide high accurate trajectory data.
- Yet, it has a number of drawbacks such as[3,4]:
  - Subjects need to physically visit the mocap laboratory
  - Requires the use of skin-attached reflective markers, which can interfere with natural gait
  - High cost

[1] Dutta, T. (2012). Evaluation of the Kinect™ sensor for 3-D kinematic measurement in the workplace. Applied ergonomics, 43(4), 645-649.
[2] Vlasic, D. et al. (2007). Practical motion capture in everyday surroundings. In ACM transactions on graphics (TOG) (Vol. 26, No. 3, p. 35). Acm.
[3] Fern'ndez-Baena et al. (2012, September). Biomechanical validation of upper-body and lower-body joint movements of kinect motion capture data for rehabilitation treatments. In 2012 fourth international conference on intelligent networking and collaborative systems (pp. 656-661). IEEE..
[4] Sandau, M et al. (2014). Markerless motion capture can provide reliable 3D gait kinematics in the sagittal and frontal plane. Medical engineering & physics, 36(9), 1168-1175..

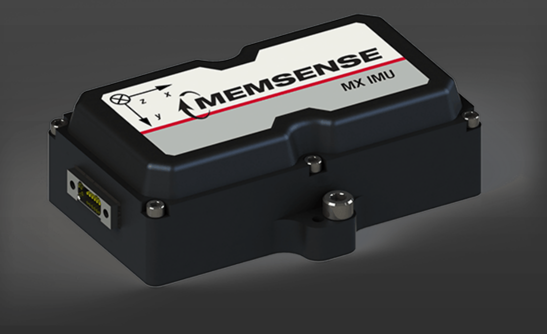
# Force Platforms

- On the other hand, FPs has its own set of limitations:
  - High financial burden
  - Require a dedicated gait lab
  - Limited capture area
  - Targeting can affect natural gait pattern[1]

[1] Challis, J. H. (2001). The variability in running gait caused by force plate targeting. Journal of Applied Biomechanics, 17(1), 77-83.

# Marker-less 3D MoCap Alternatives

- Inertial Measurement Units (IMUs)
  - Self-contained system that measures linear & angular motion
  - Hard to estimate accurate position data
  - Magnetic interference can disturb high quality data[1]

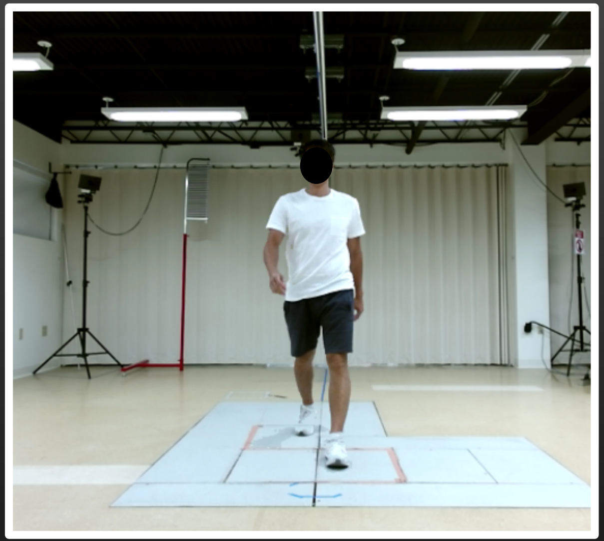



- RGB-Depth sensors
  - Depth data
  - Easy to use
  - Cost-effective
  - Does not require the use of skin-attached markers

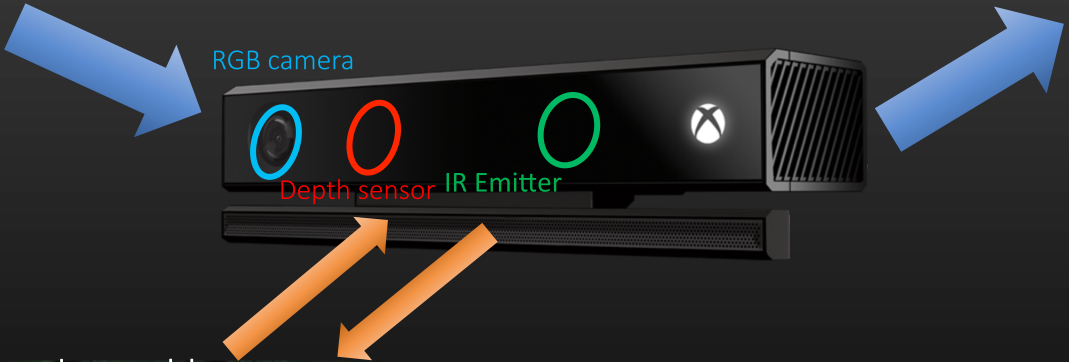
[1] Robert-Lachaine, X., Mecheri, H., Larue, C., & Plamondon, A. (2017). Effect of local magnetic field disturbances on inertial measurement units accuracy. Applied ergonomics, 63, 123-132.

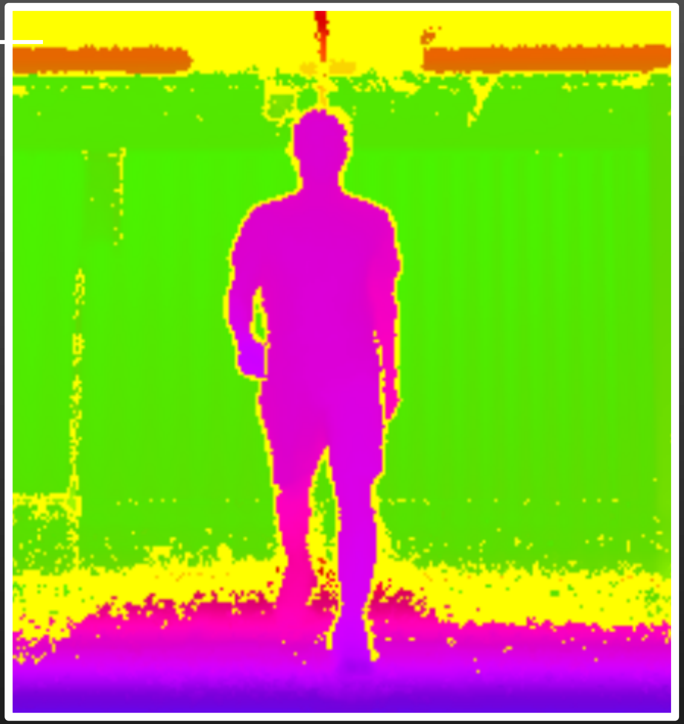
# RGB-Depth Sensors (Microsoft XBOX Kinect v.2)

- How does the XBOX Kinect work?



Scene



Scene depth map

Infrared speckle pattern

Color camera: 1920×1080 at 30 Hz

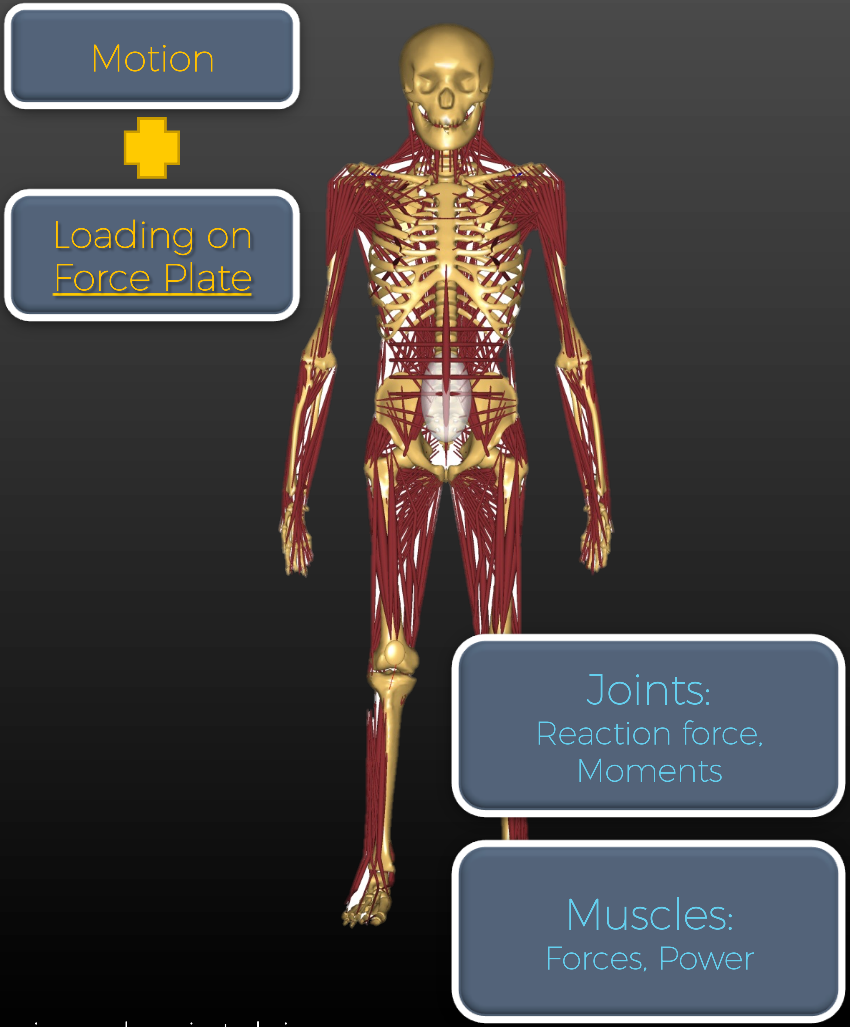
Depth camera: 512×424

Field of view: 70 (H) ×60 (V) degree

Skeleton joints defined: 26 joints

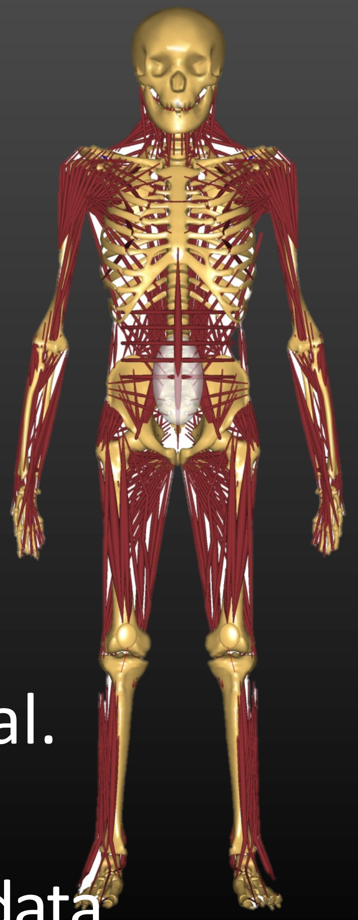
# Inverse Dynamic Analysis

- IDA using musculoskeletal modeling is a powerful tool, which is utilized in a range of applications to estimate forces in ligaments, muscles, and joints, non-invasively[1].
- Typically, this can be achieved through top-down or bottom-up approaches, depending on the ability to measure external forces.




[1] Chowdhury, S., & Kumar, N. (2013). Estimation of forces and moments of lower limb joints from kinematics data and inertial properties of the body by using inverse dynamics technique. Journal of Rehabilitation Robotics, 1(2), 93-98.

# Estimation of GRFs



Estimate of GRF&Ms under both feet can be achieved by:

- Minimize joint moments (Audu et al. 2003, 2007)

  -Only standing positions

- Artificial Neural Network (Choi et al. 2013)

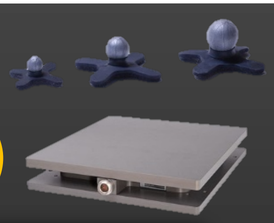
  -Model inputs require comprehensive analysis

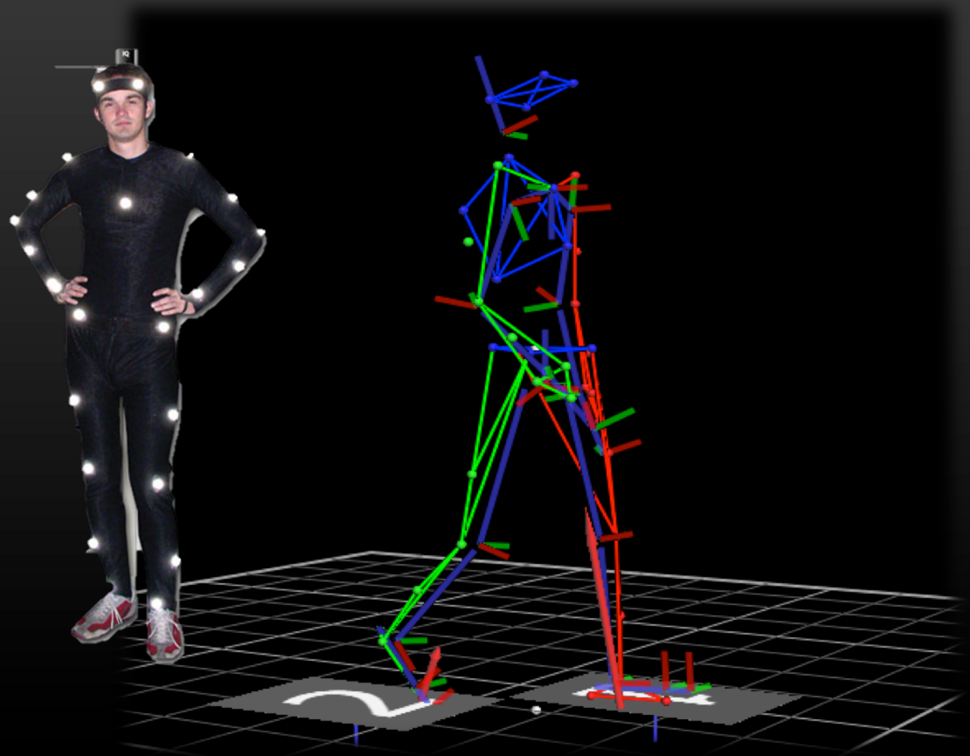
- **Dynamic contact model and muscle recruitment** (Fluit et al. 2014)

  -Universal method, scaled model and requires kinematic data only, and validated for activities of daily living

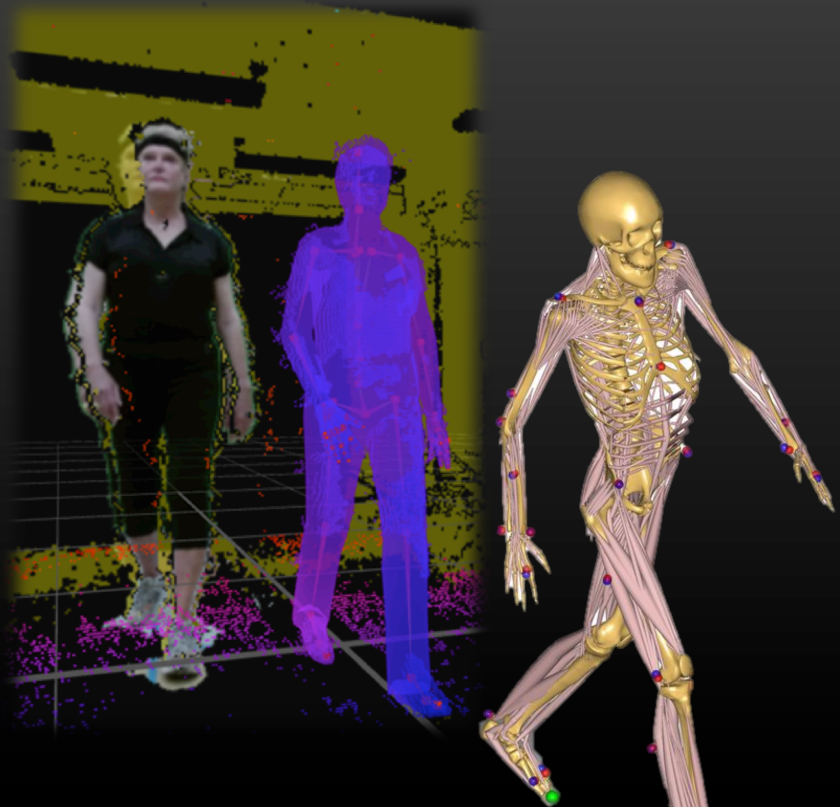
# Estimation of GRFs

Laboratory-based
(markers/ force plates)





Clinic/Home-based
(Marker-less & no force plates)

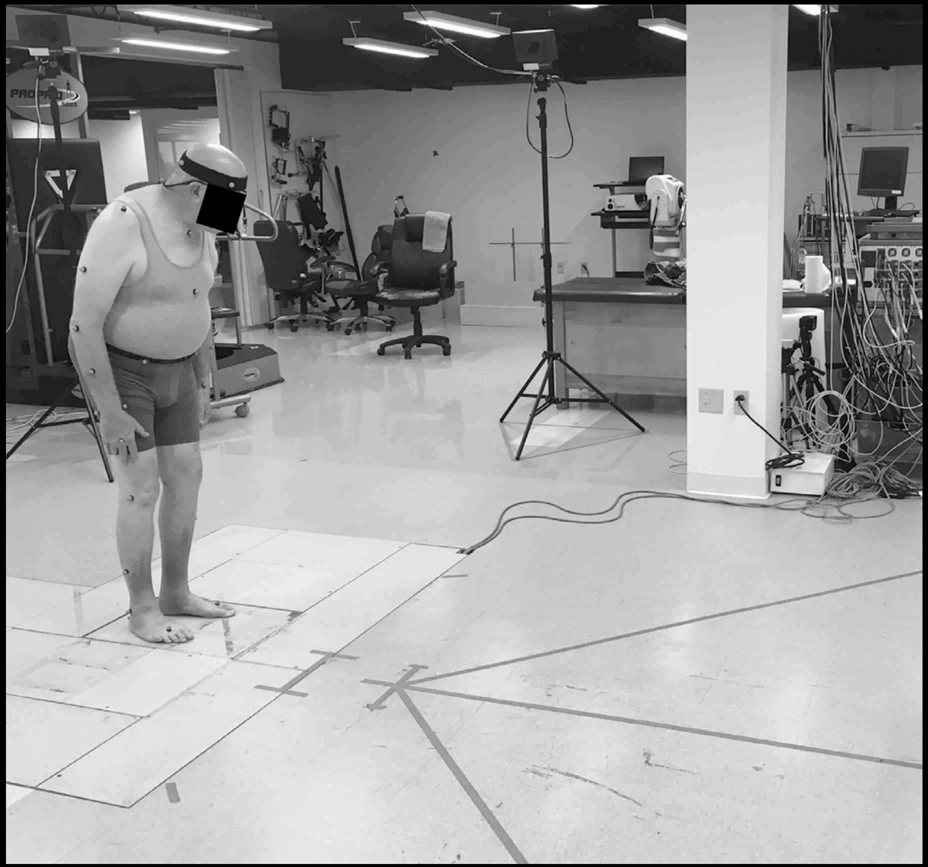


# The Aim

- In our previous work[1], the Kinect was able to detect differences in gait kinematics and spatiotemporal parameters between elderly PD patients and age-matched healthy group.
- In this study, we aimed to validate the use of an AnyBody musculoskeletal model driven by a single depth sensor to predict GRFs during forward gait in elderly patients with PD.
- So, this approach is an attempt to enhance the quality of clinical gait assessment in this population while ensuring cost effectiveness and feasibility of implementation in clinical settings.

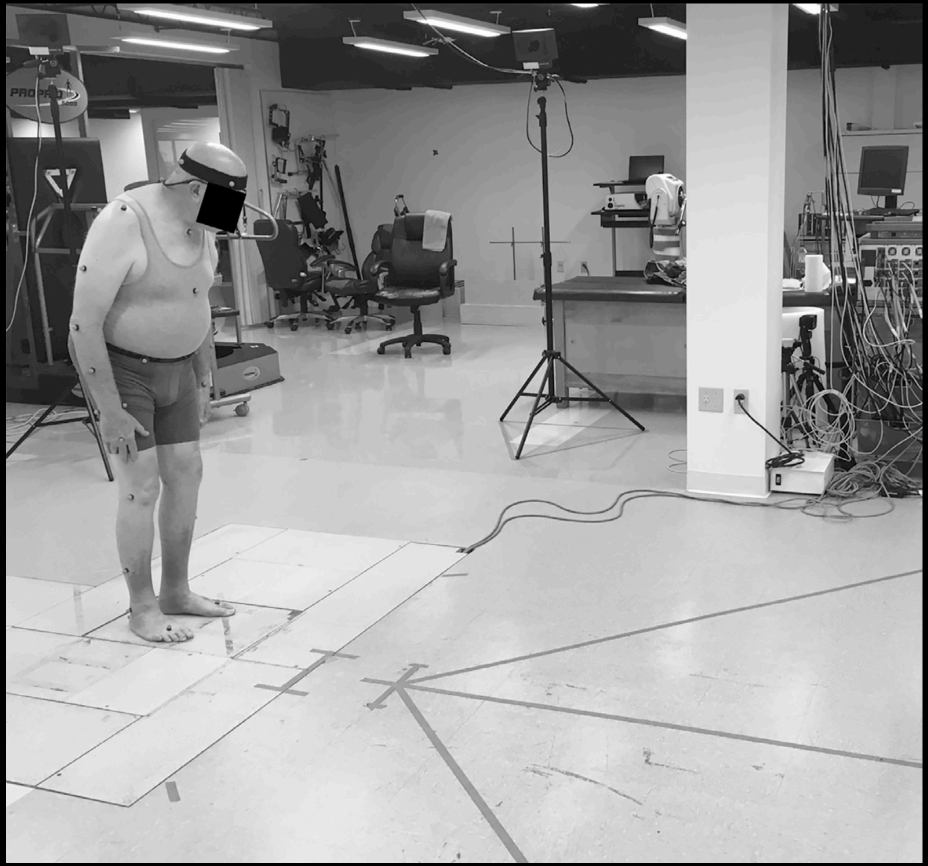
[1] Eltoukhy, M., Kuenze, C., Oh, J., Jacopetti, M., Wooten, S., & Signorile, J. (2017). Microsoft Kinect can distinguish differences in over-ground gait between older persons with and without Parkinson's disease. *Medical engineering & physics*, *44*, 1-7.

# METHODS



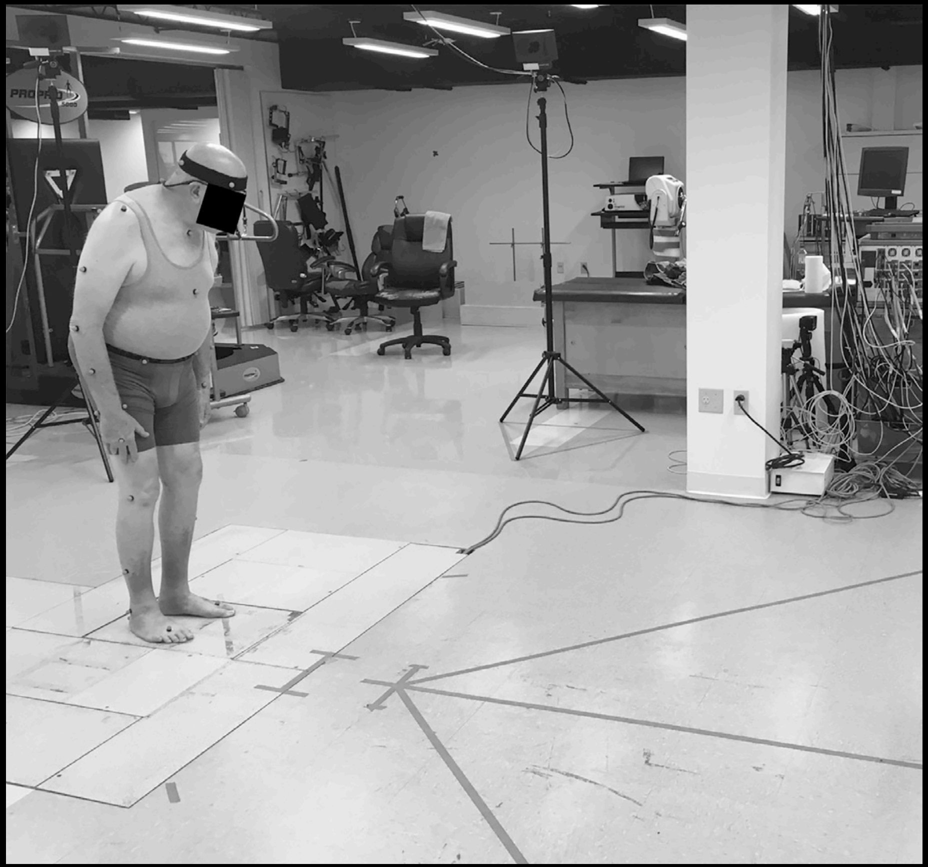
# Experimental Procedure

- Over-ground forward gait trials.
- 10-meter walkway, one gait cycle was analyzed.
- Single RGB-D sensor (Kinect v.2): placed at 2.5 m (distance) and 0.75 m (height)
- Two floor-embedded Kistler force plates.



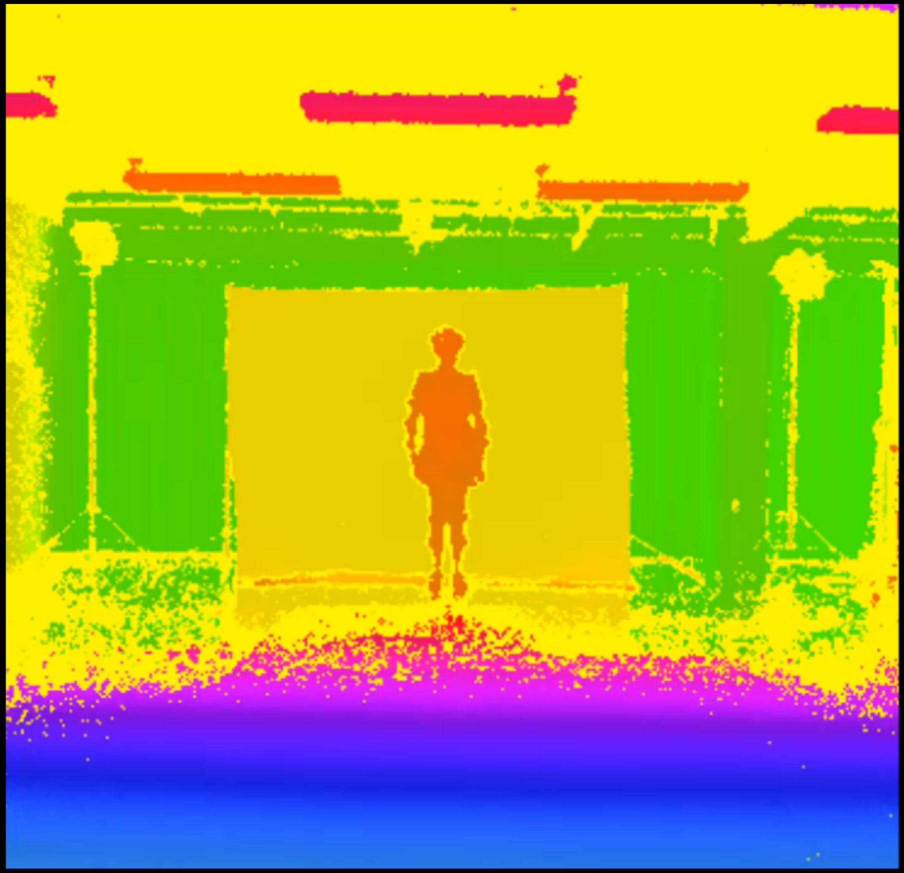
# Experimental Procedure

- Nine elderly participants diagnosed with Parkinson's disease (age =71.0 ±5.6 yrs, height =165.4 ±11.3 cm, weight =70.8 ±16.7 kg), were recruited for this study.
- Subjects were mildly to moderately impaired (H&Y stages I-III) and had a score of 24 or above on the Folstein Mini-Mental State Examination.



# Experimental Procedure

- All patients were capable of ambulation for at least 50 feet without an assistive device.
- PD patients walked barefoot at their normal walking speed.

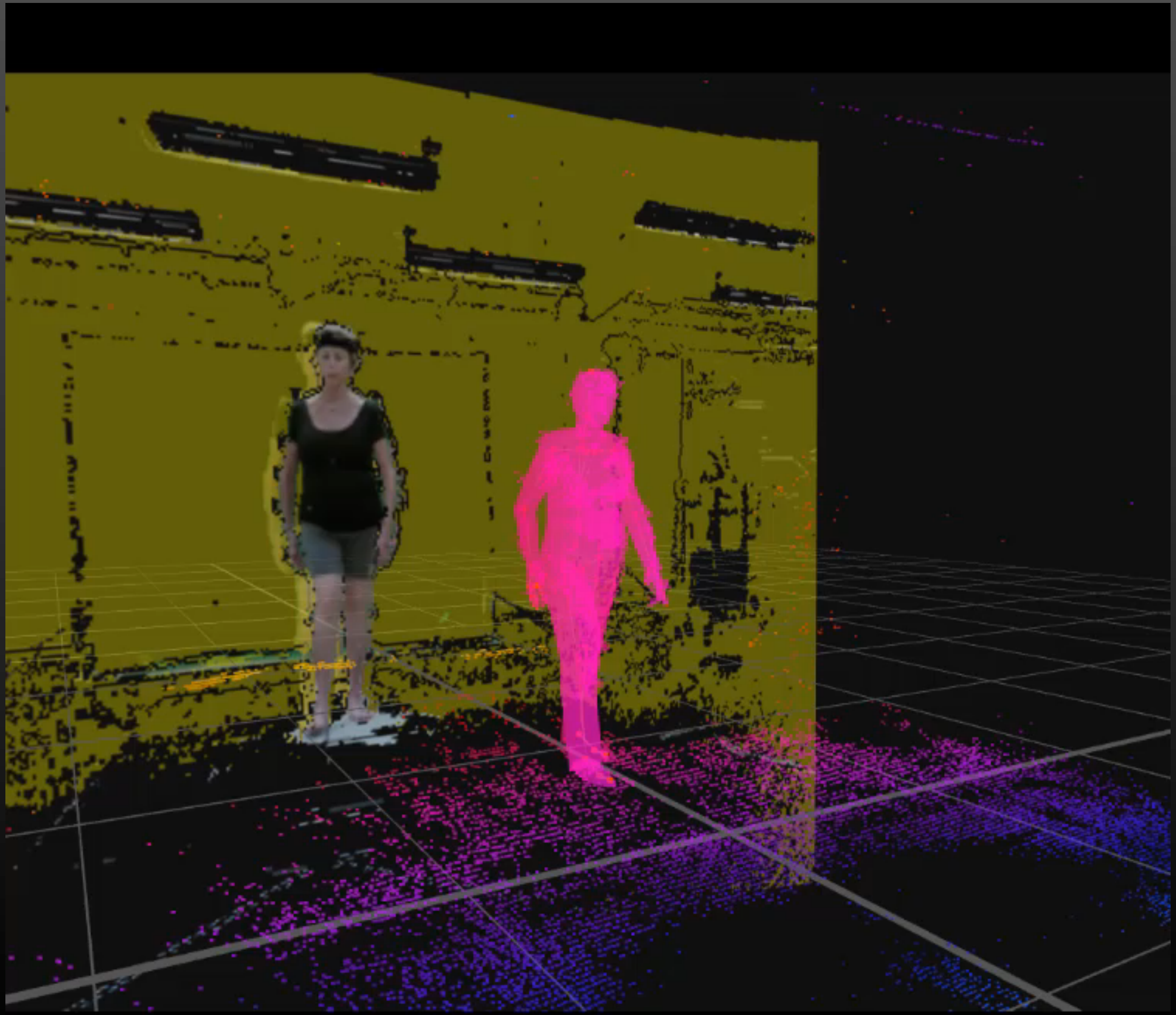


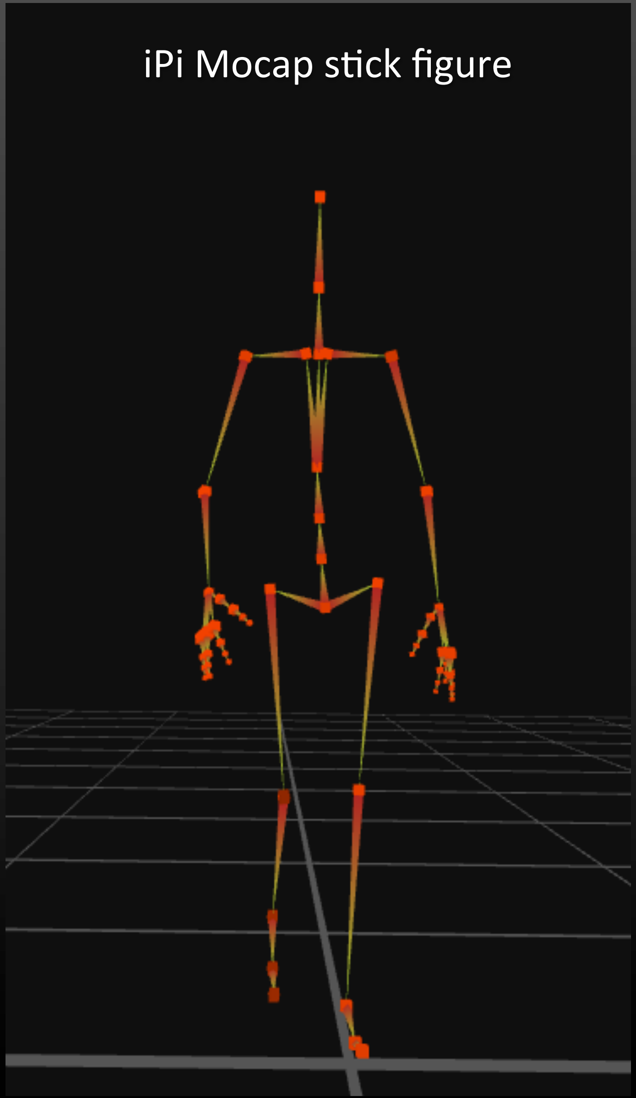
Over-ground gait

# Data Acquisition

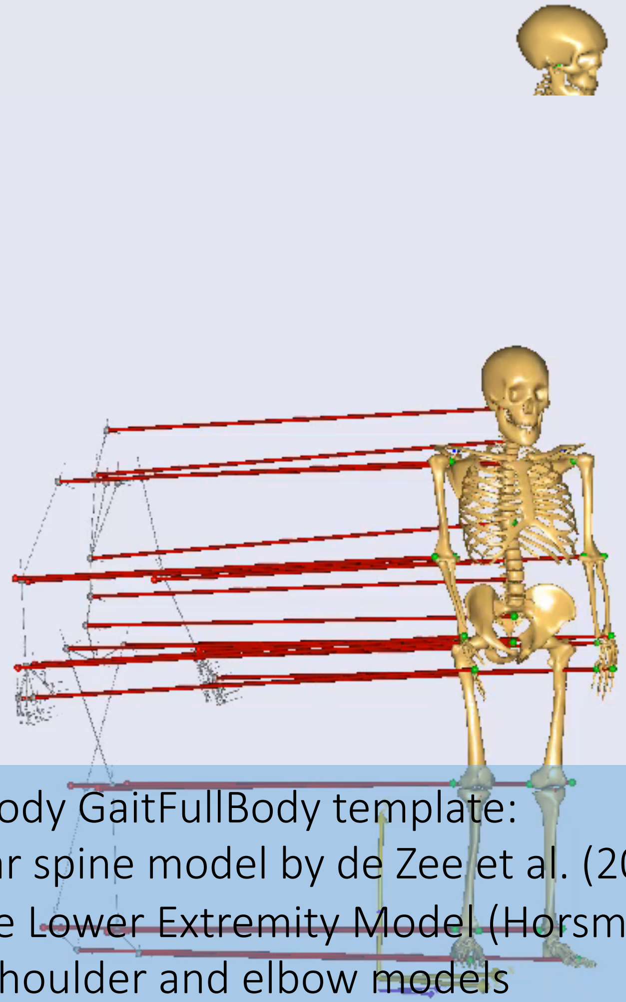
- Force Platforms
  - Two floor-embedded Kistler force platforms
  - Low-pass filtered with 10 Hz
- Depth sensor:
  - Single Microsoft Kinect v.2 RGB-D sensor
  - Sampling rate of 30 Hz

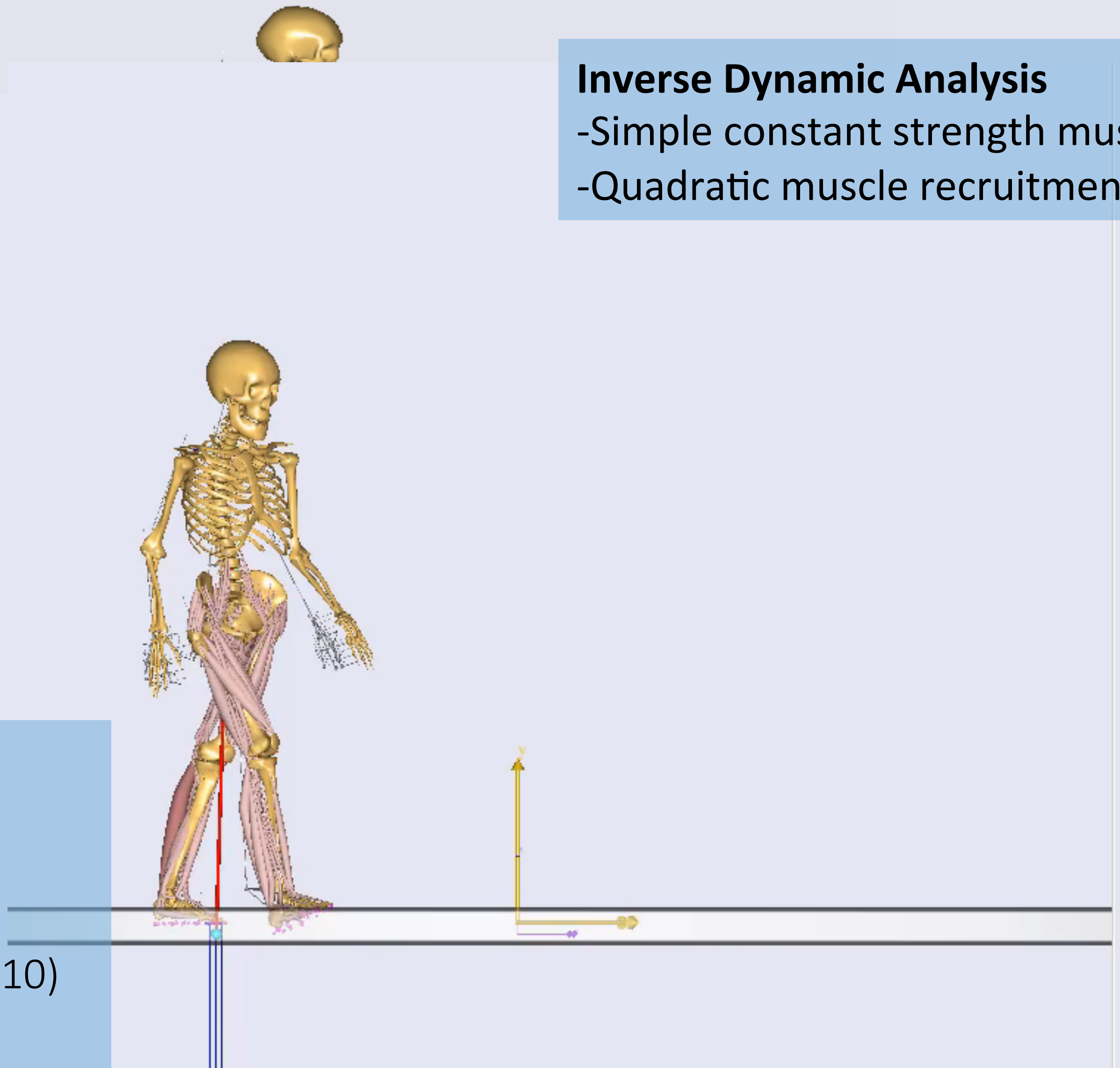
# RGB-D Sensor Data Analysis Workflow





# Musculoskeletal Modeling (Kinect sensor driven)





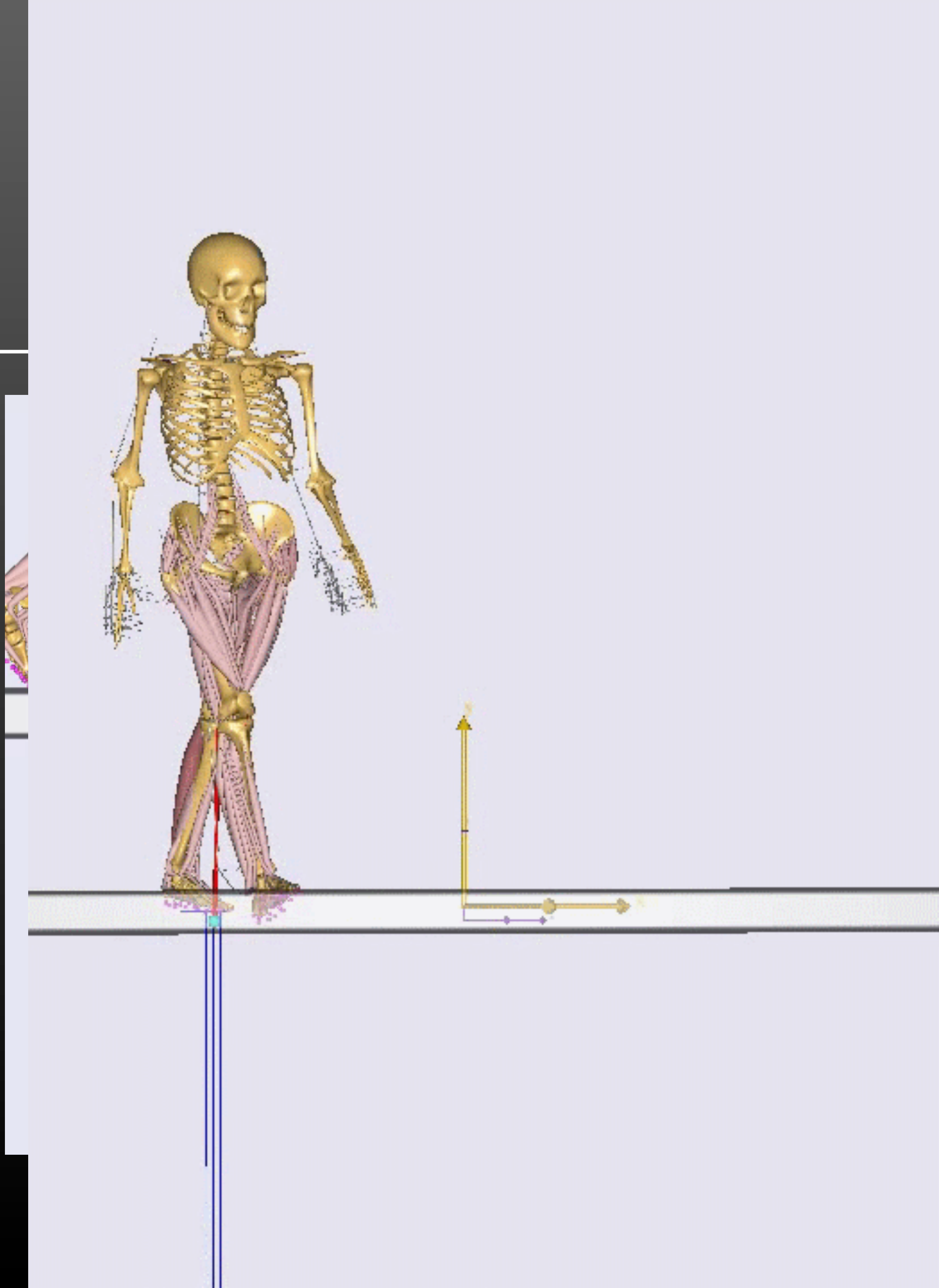
**Inverse Dynamic Analysis**
-Simple constant strength muscles
-Quadratic muscle recruitment

The AnyBody GaitFullBody template:
- Lumbar spine model by de Zee et al. (2007)
- Twente Lower Extremity Model (Horsman et al., 2007)
- Delft shoulder and elbow models

Model scaling & Kinematic analysis (Anderson et al. 2009, 2010)
- Adjusts segment lengths and marker coordinates

# Musculoskeletal Modeling (Kinect sensor driven)

- GRFs prediction using a modified version of the work by Skals et al.:
  - 25 contact points defined under each foot
  - Five artificial muscle-like actuators in each contact point
  - Solved as part of  muscle recruitment algorithm

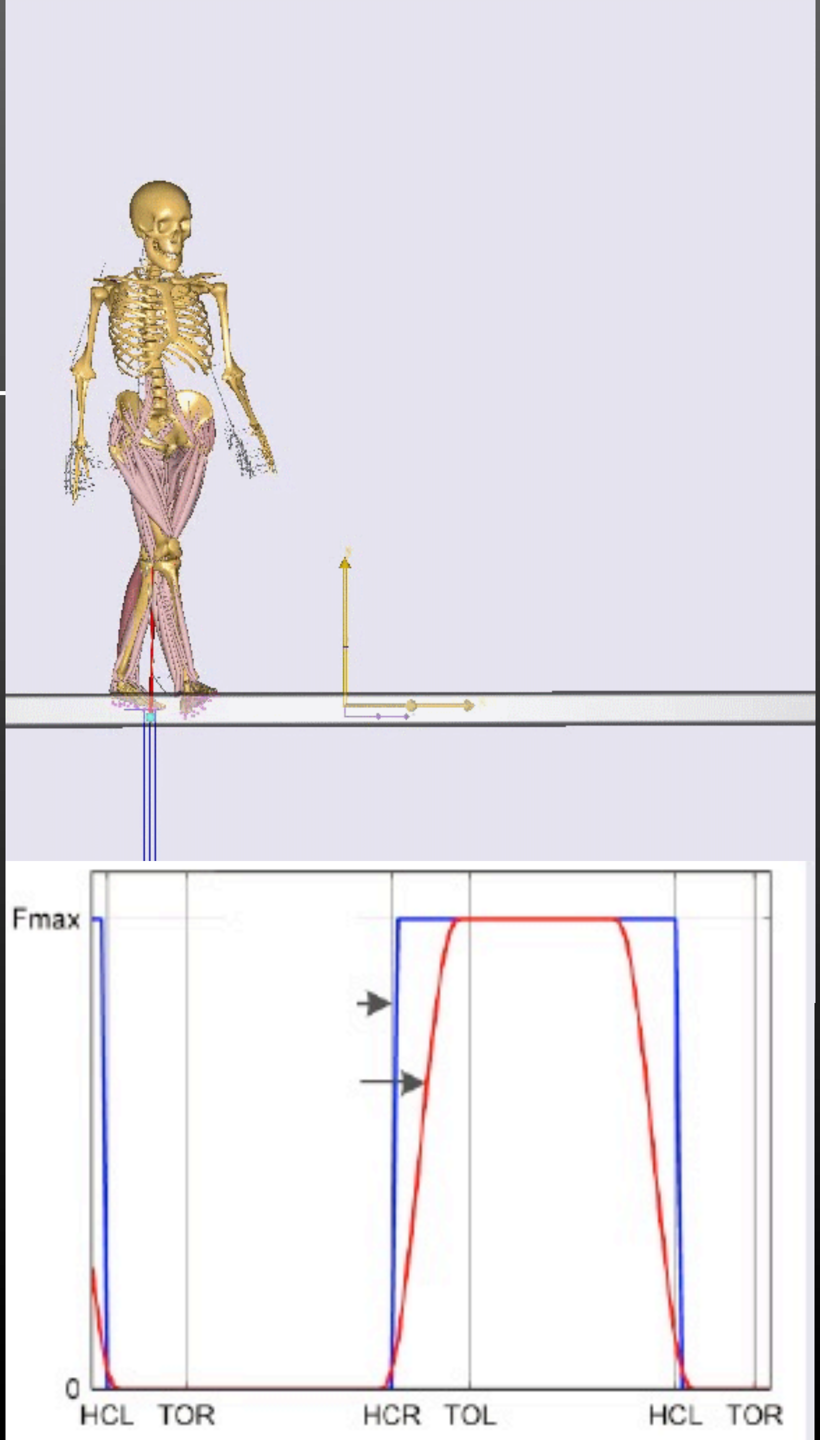


# Musculoskeletal Modeling (Kinect sensor driven)

- GRFs prediction using a modified version of the work by Skals et al.:
  - Fmax, zlimit, and vlimit (contact parameters)
  - Contact when:

    Node inside contact area &

    Node velocity small.
  - Transition smoothing based on node position and velocity was implemented



# RESULTS

Measured vs. Predicted GRFs

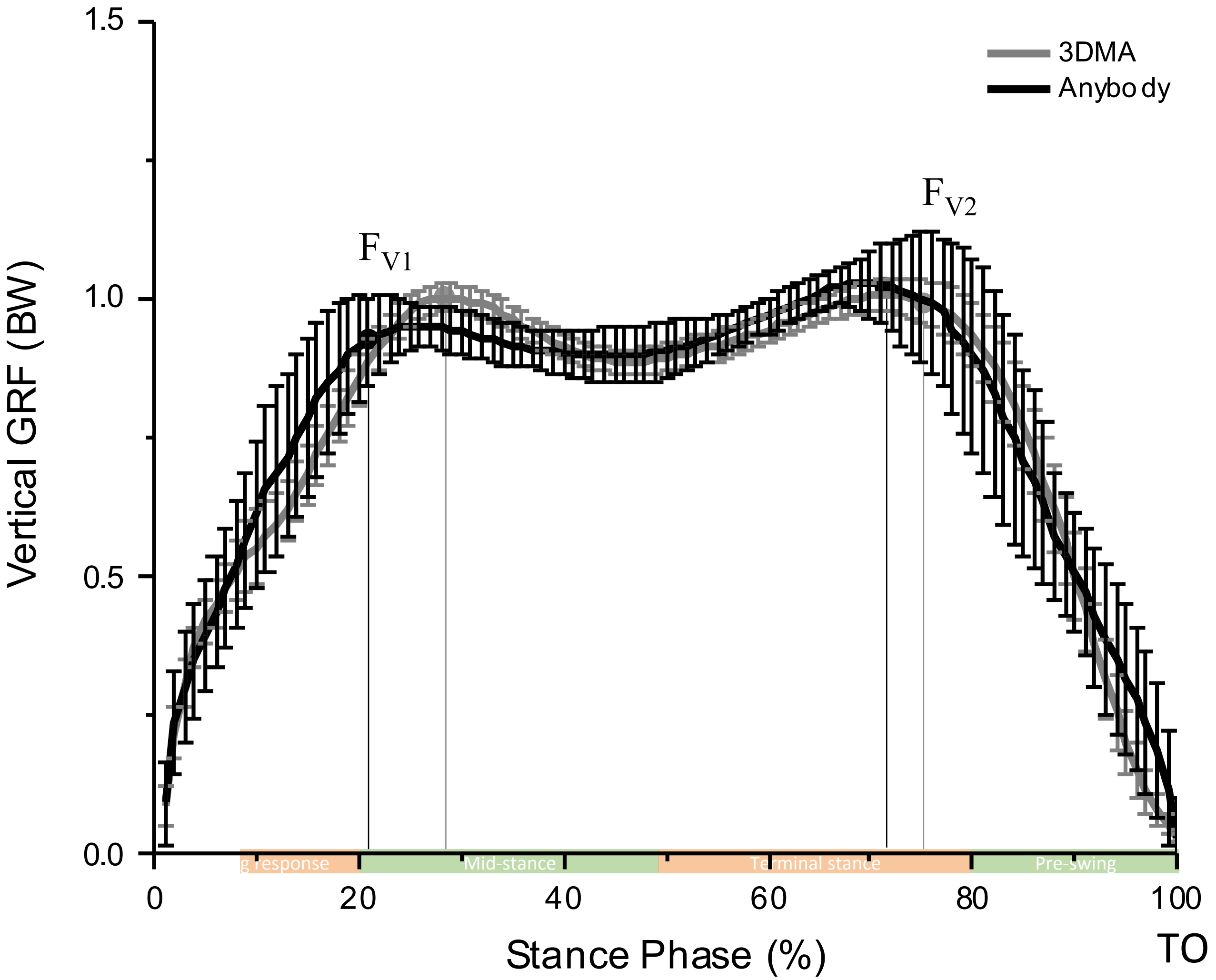
# Over-ground Gait

Vertical GRF

- Small magnitude differences
- Poor agreement and consistency at peak $GRF_{V1}$ and $GRF_{V2}$

*combined sample (Unit: N/BW)

| | Measured MeanSD | Predicted MeanSD | Agreement ( ±95%CI) | Consistency ( ±95%CI) |
|---|---|---|---|---|
| $GRF_{V1}$ | 1.02±0.03 | 1.02±0.03 | 0.02 (0.81) | 0.01 (0.79) |
| $GRF_{V2}$ | 1.01±0.05 | 1.10±0.04 | 0.05 (0.57) | 0.12 (0.70) |



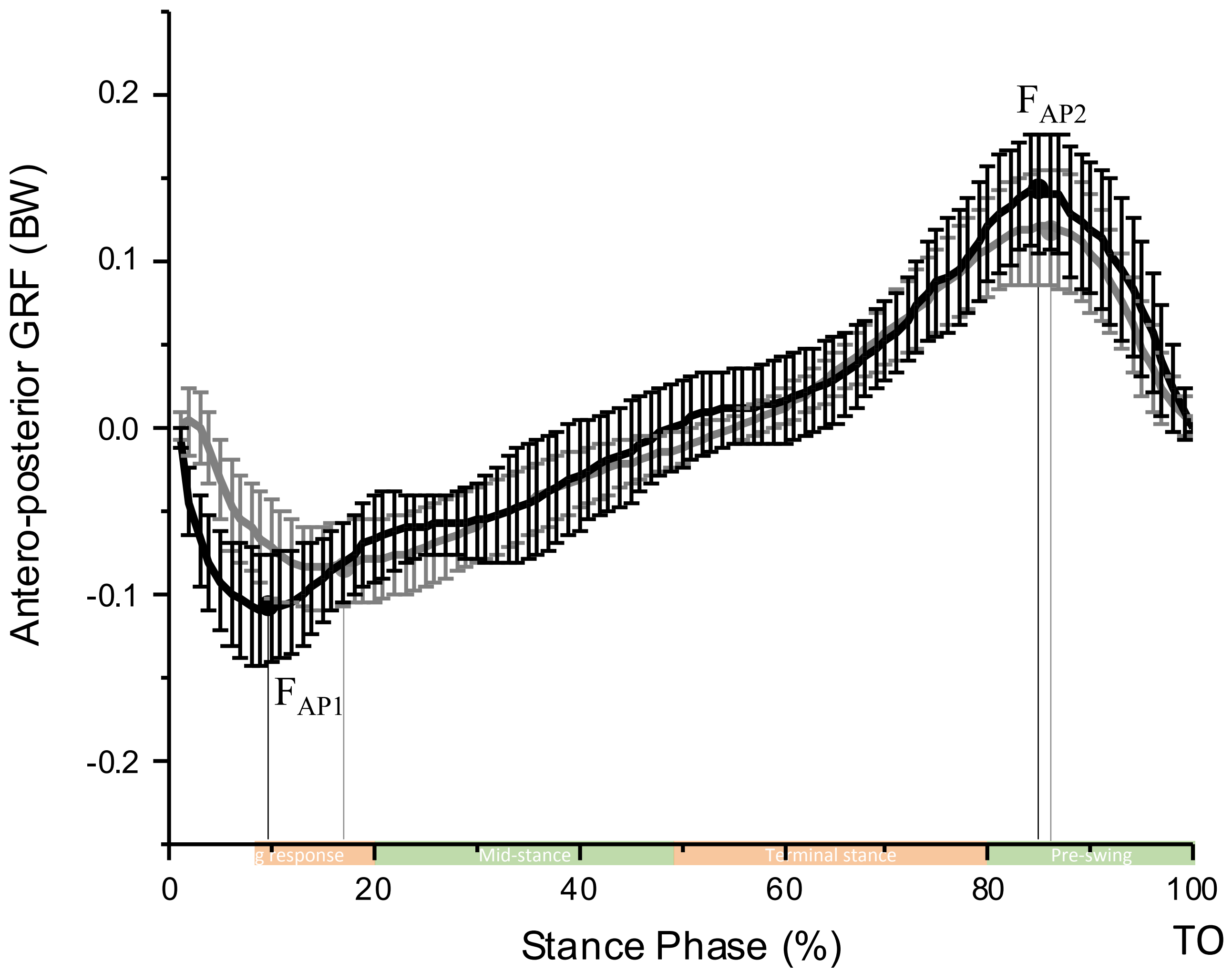
# Over-ground Gait

## Antero-posterior GRF

- Good agreement and excellent consistency at peak $GRF_{V1}$ and $GRF_{V2}$

*combined sample (Unit: N/BW)

| | Measured MeanSD | Predicted MeanSD | Agreement | Consistency |
|---|---|---|---|---|
| **$GRF_{AP1}$** | **-0.10±0.03** | **-0.13±0.03** | 0.63† (0.29) | 0.84† (0.13) |
| **$GRF_{AP2}$** | **0.12±0.04** | **0.16±0.04** | 0.75* (0.20) | 0.89* (0.09) |

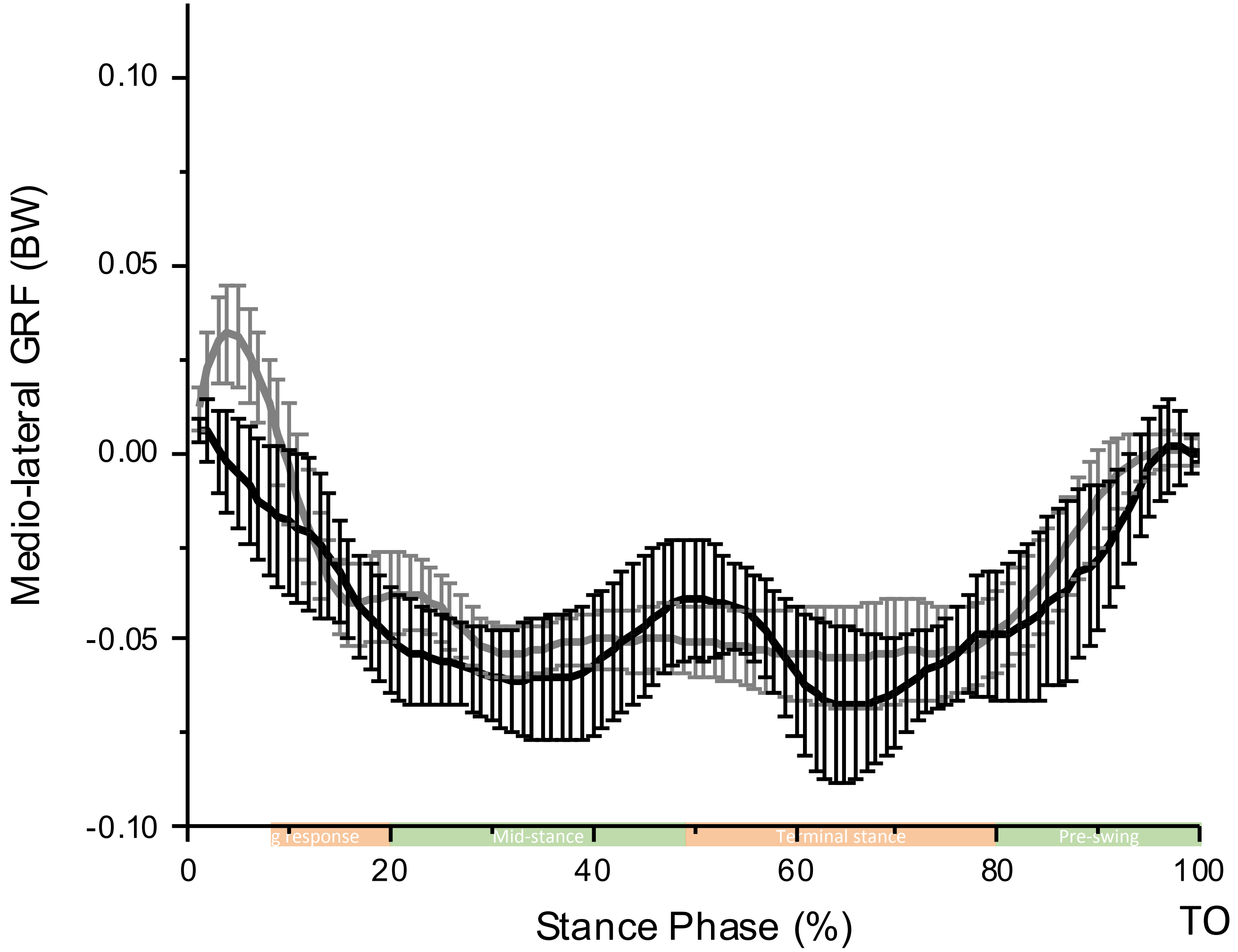


# Over-ground Gait

## Medio-lateral GRF

*combined sample (Unit: N/BW)

| | Measured MeanSD | Predicted MeanSD | Agreement | Consistency |
|---|---|---|---|---|
| $GRF_{ML1}$ | -0.06±0.01 | -0.08±0.01 | | |
| $GRF_{ML2}$ | -0.06±0.01 | -0.09±0.02 | | |



# Results

- Peak GRF in general, and $GRF_v$ in particular, is a measure sensitive to progressive changes in gait patterns that are often a hallmark of disease progression. For instance, a reduction in the second peak of the $GRF_v$.
- The predicted GRF plots obtained showed similar patterns to the measured ones, especially the vertical and horizontal GRFs.
- A maximum difference between the predicted and measured average peak vertical GRFs of 8.3% was obtained, yet, higher overestimations in the peak $GRF_{AP}$ values were observed.

# Results

- The less consistent pattern of the predicted $GRF_{ML}$ as compared to the measured values; was especially apparent during the loading response phase of the gait cycle.
- This lack of $GRF_{ML}$ prediction accuracy in general can be explained by the absence of the eversion/inversion kinematics driver in the foot model used.

# Results

- The difference between the measured and predicted $GRF_V$ ranged between 0.02 and 0.15 N/BW.
- To the best of our knowledge, no *minimal clinically accepted error* of the Parkinsonian gait ground reaction forces has been established that can be used to relate our findings to potential clinical applications.
- Thus, we used a public gait database[1], consists of GRF V data records of 93 PD and 73 healthy elderly subjects, to calculate the average difference between the gait peak $GRF_V$.

[1] HausdorffJ, etal.Gait inparkinson'sdisease. NationalInstituteof Health, Na- tional Parkinson Foundation, and the Parkinson's Disease Foundation; 2005. Retrieved from: https://physionet.org/physiobank/database/gaitpdb.

# Results

- The estimated average normalized $GRF_V$ difference between the healthy and PD groups was 0.51 N/BW.
- So, the maximum error in the predicted $GRF_V$ was more than three-folds less than the average $GRF_V$ difference between the Parkinsonian gait and the normal gait values produced by age-matched healthy population which indicates that the proposed approach can detect deviations in the clinically-relevant $GRF_V$ values.

# Discussion & Conclusions

- Accurate estimates of peak GRFs are highly dependent on the force component  being evaluated.
- Discrepancies can be due to:
  - -Signal-to-noise ratio
  - -Simple knee model (hinge joint)
- Areas to improve:
  - -Foot-ground contact determination
  - -More detailed knee and foot model

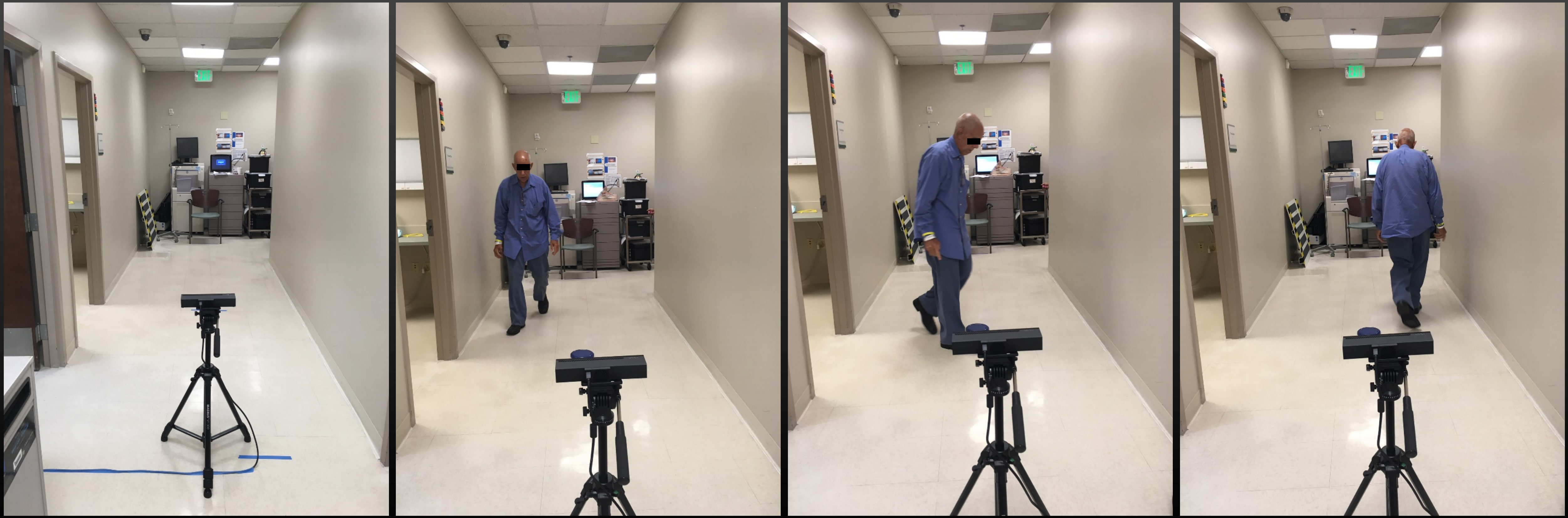
# Discussion & Conclusions

- Overall, the observed GRF outcome measures indicated altered joint loading patterns, which would enable better understanding of gait dysfunction in PD patients.
- AnyBody GRF prediction using depth sensors has the potential to be used in clinical settings, eliminating the need for force platforms

# Discussion & Conclusions

- The ability to accurately assess GRF parameters using low cost technology that does not require the outfitting of participants, especially those at high risk of fall such as individuals with PD, with cumbersome equipment that may interfere with normal gait patterns represents a meaningful advance in this area of research.

# Application



PD patient performing TUG test at the Neurology Clinic, Miller School of Medicine, UM.

# More Info

- Oh, J., Eltoukhy, M., Kuenze, C., Andersen, M. S., & Signorile, J. F. (2019). Comparison of predicted kinetic variables between Parkinson's disease patients and healthy age-matched control using a depth sensor-driven full-body musculoskeletal model. *Gait & posture*, *76*, 151.
- The model is available at:

https://github.com/AnyBody/AnyKinectModel

This work was funded by the Parkinson’s Foundation
(Grant Number: PF-PLA-1710)

# Thank you

## www.anybodytech.com

- Events, dates, publication list, ...

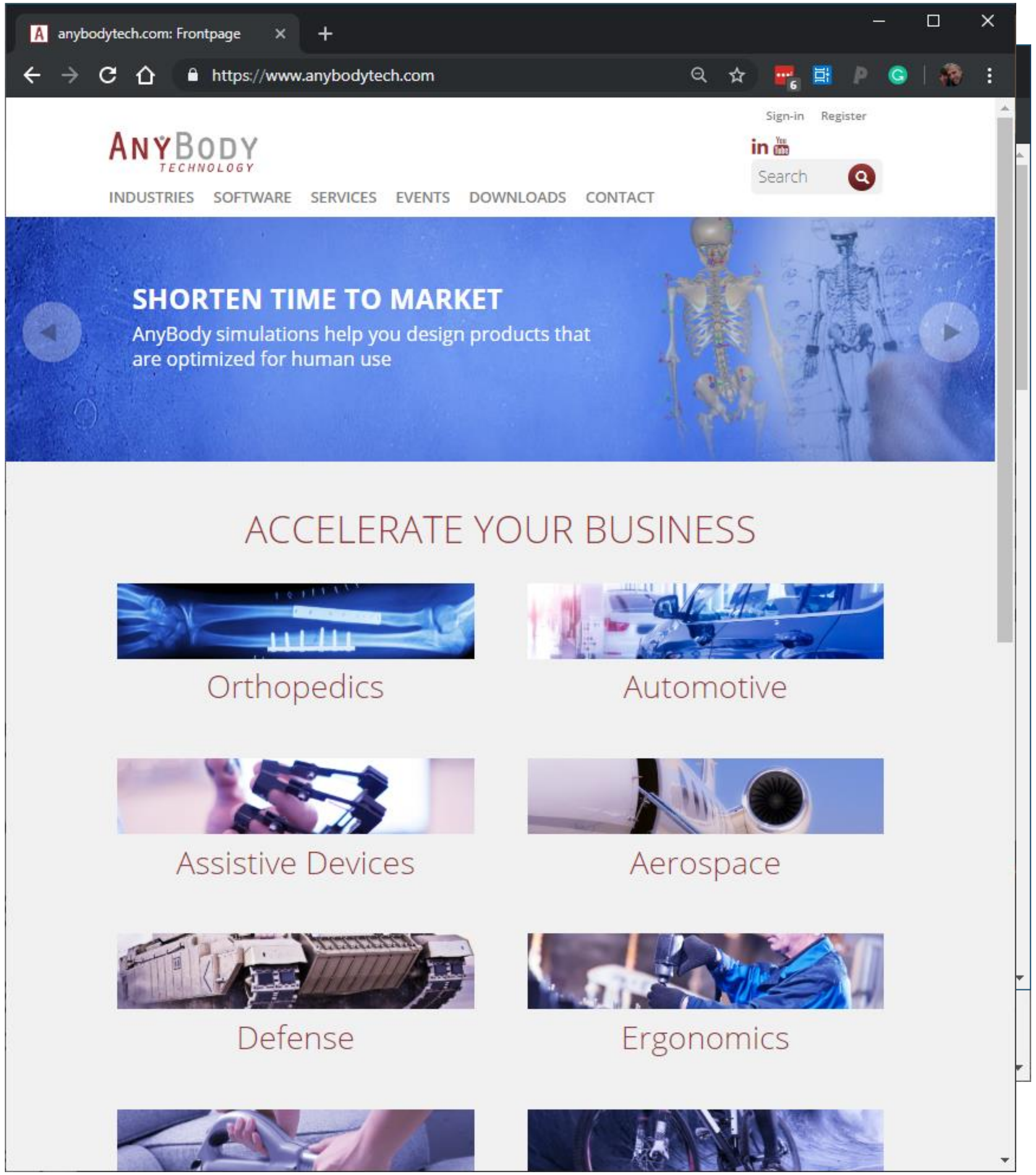
## www.anyscript.org

- Wiki, Forum, Repositories

## Events:

**30 MAR-1 APR:** Meet us and other wearable robotics professionals at **WearRAcon** in Scottsdale, AZ

**Meet us?** Send email to sales@anybodytech.com



# Time for questions: