CusToM Workshop

XSENS Force prediction

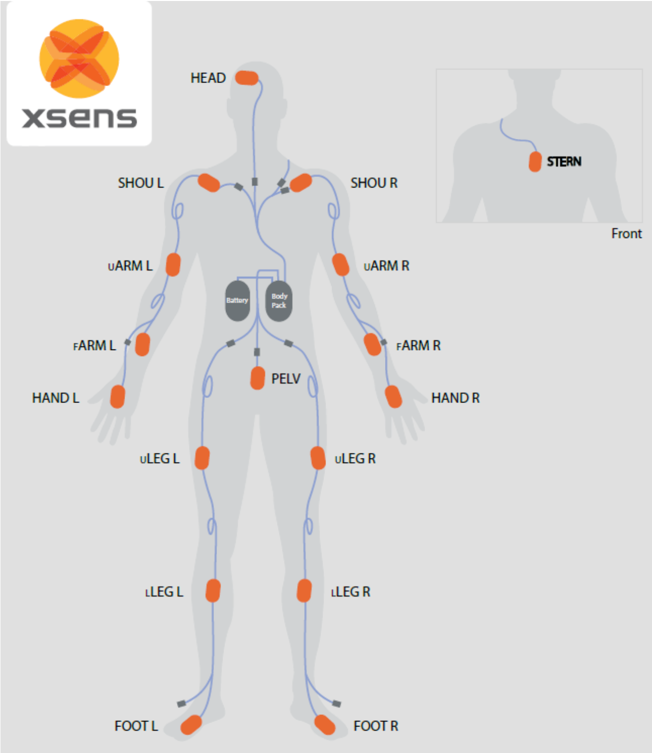
Charles Pontonnier, Pierre Puchaud

Pre-work

1. Go in `Examples/2_Tennis_Force_Prediction`

What is XSENS ?

IMU SENSORS



Full body motion capture

Motions to analyse – Tennis Service

XSENS provide the motion
What if we want to predict external forces ?

https://content.xsens.com/motion-data

Force prediction: what does this mean ?

Sometimes, you want to do dynamics without force platforms

It is therefore necessary to generate - predict the external forces on the whole motion capture to make consistent inverse dynamics

Measuring

Motion-based external forces prediction [Muller2019a, Muller 2019b]

Motivation : are we able to compute relevant dynamical information without any force measure ?
on-site ergonomics evaluation

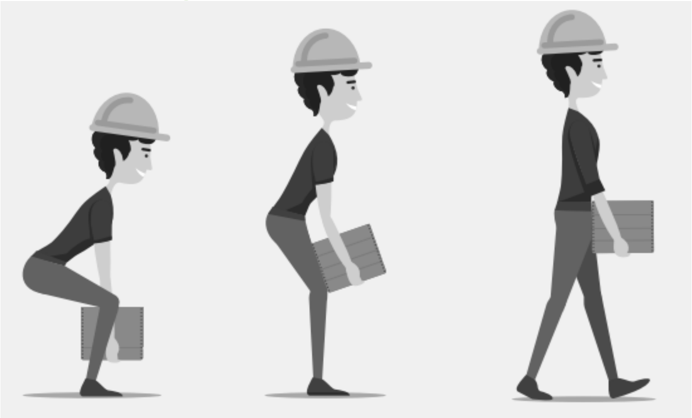
A few methods exist

- Machine learning **[Oh2013]**
- Analytical **[Koopman1995,Dijkstra2015]**
- Optimisation based **[Fluit2014,Skals2017]**

Only for Ground Reaction Forces

What about hand contact forces ?

Handling tasks



employsure.co.nz

GenerateParameters

```
>> GenerateParameters
```

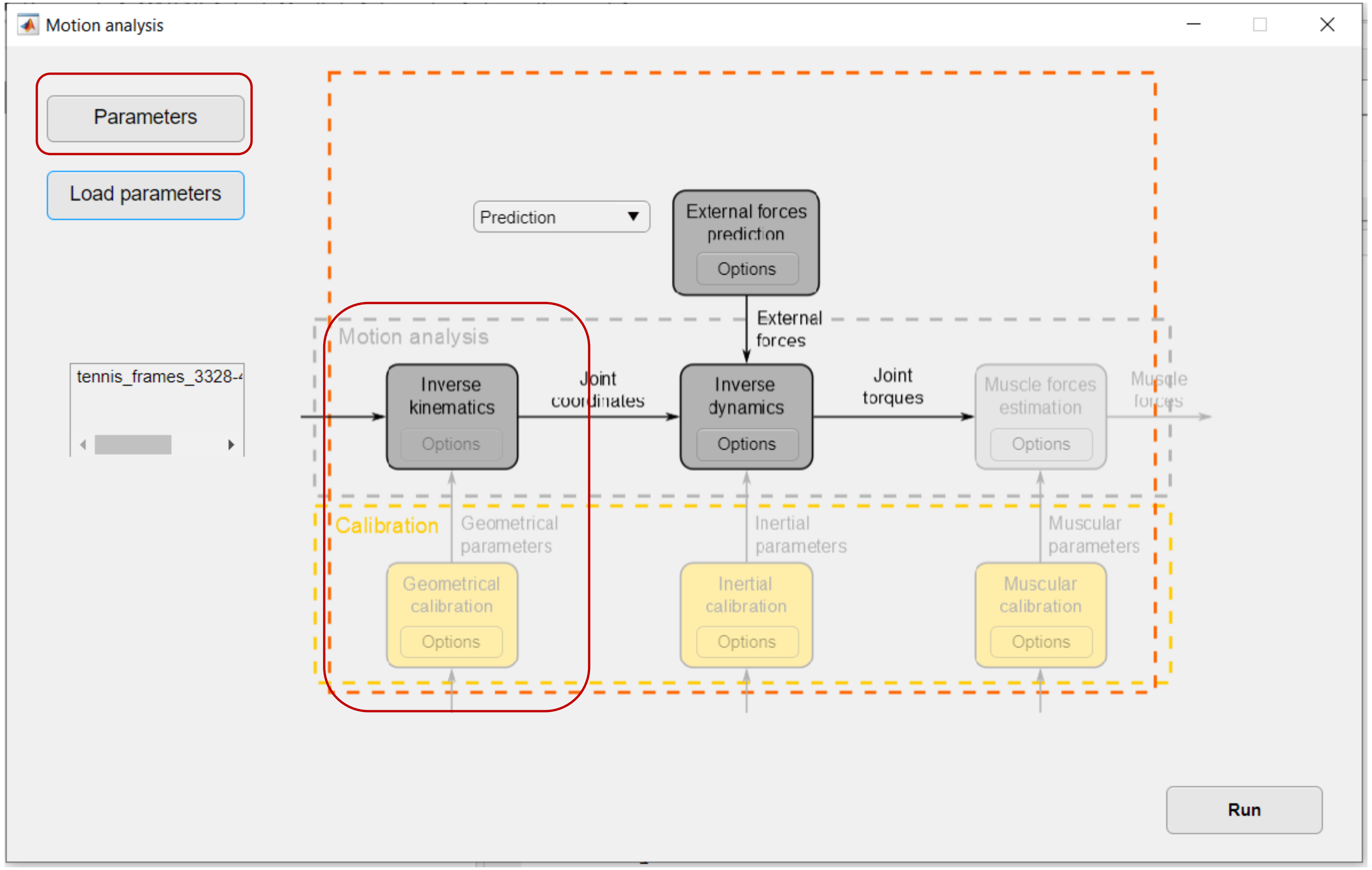
Subject’s height: 1.80m
Subject’s weight: 70 kg

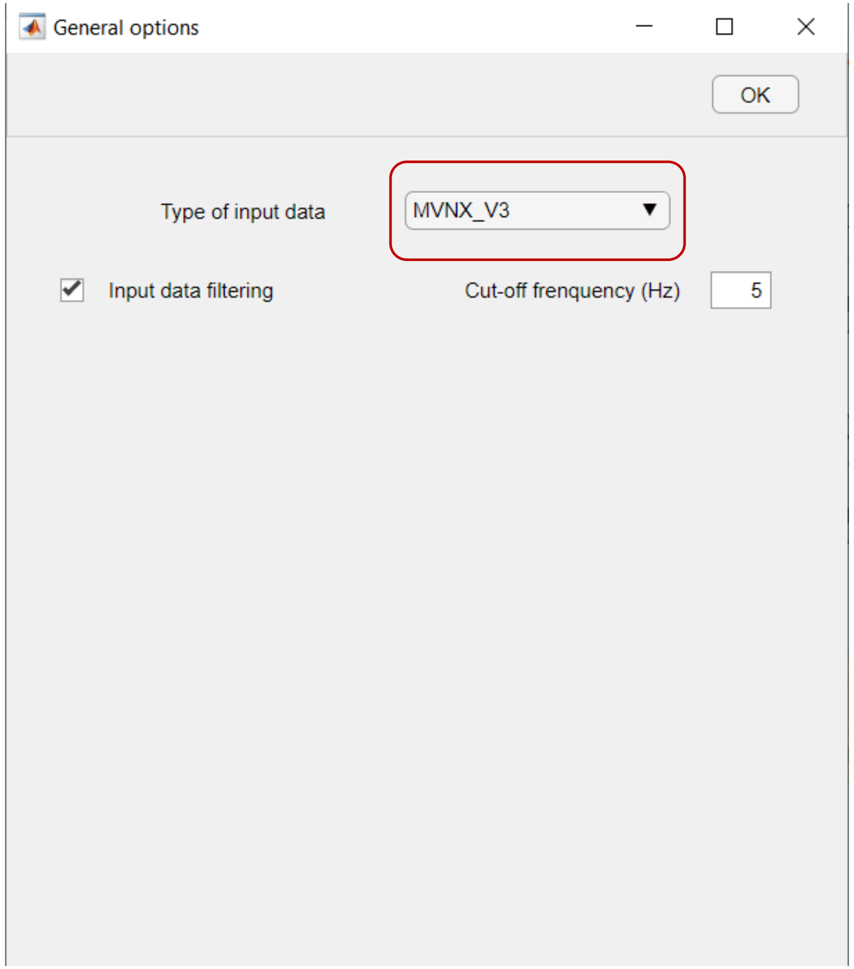
Model: Full Body

Markerset : not important

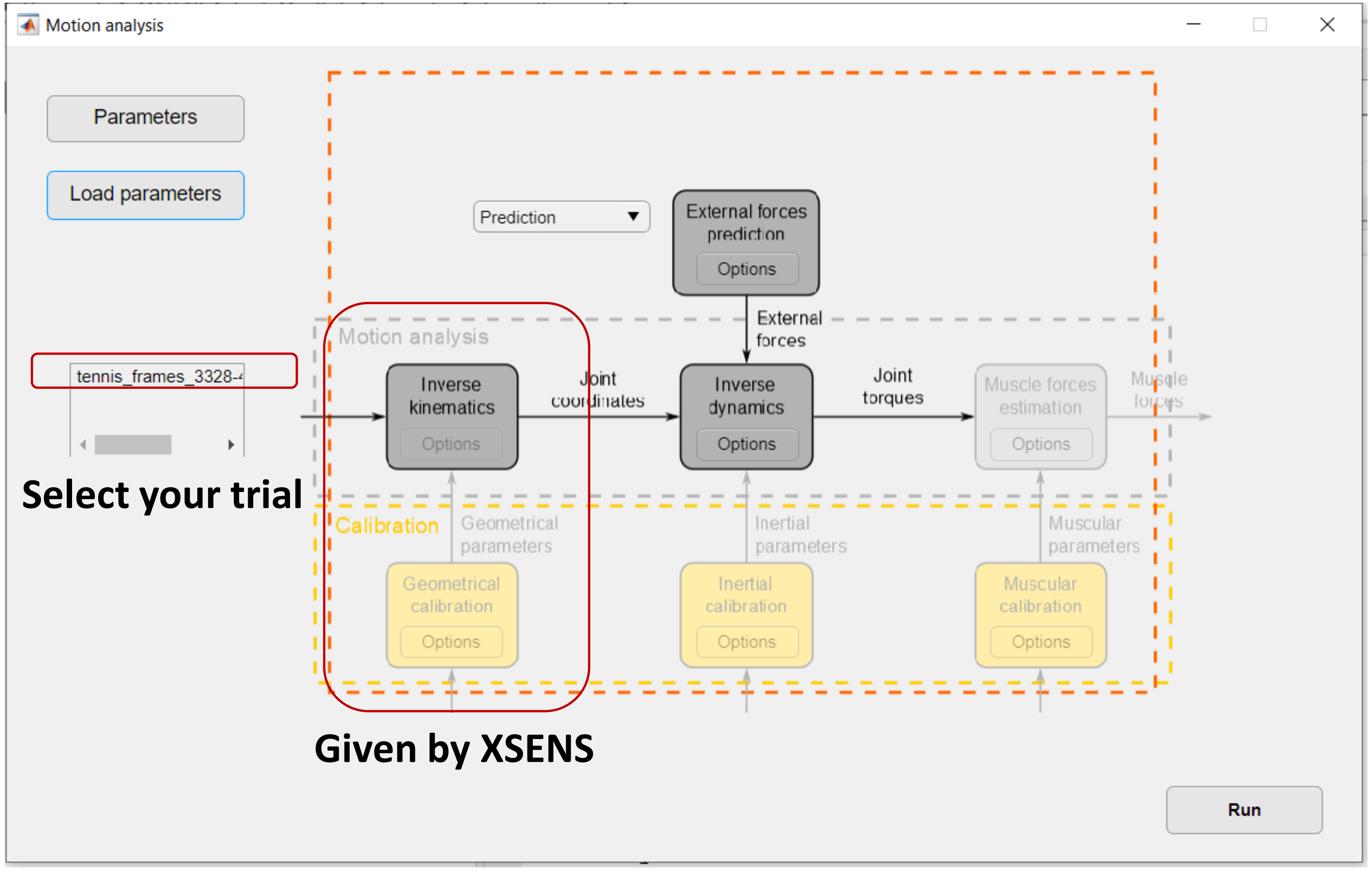
Muscle set: no muscles

AnalysisParameters





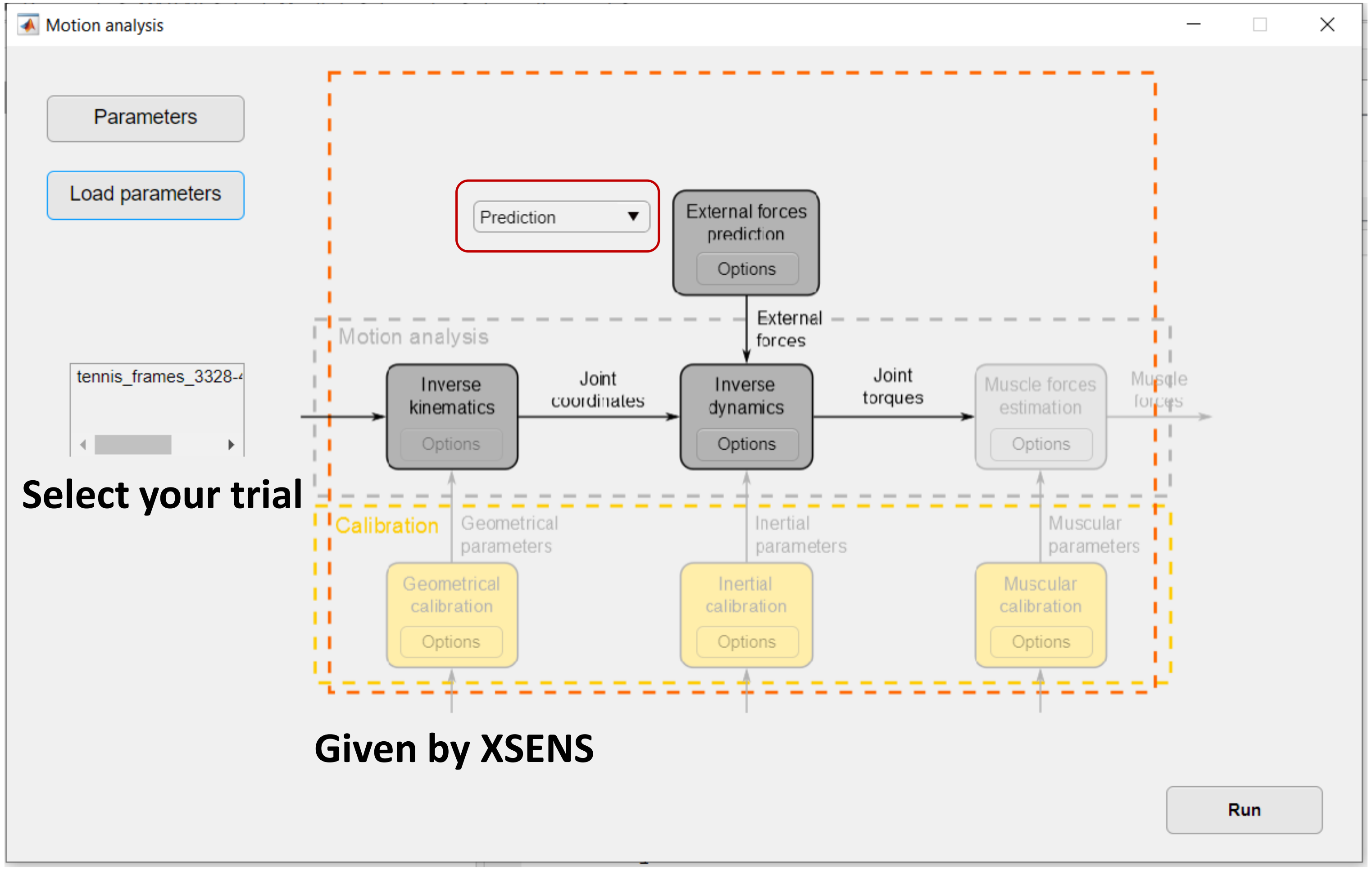
AnalysisParameters



Select your trial

Given by XSENS

AnalysisParameters



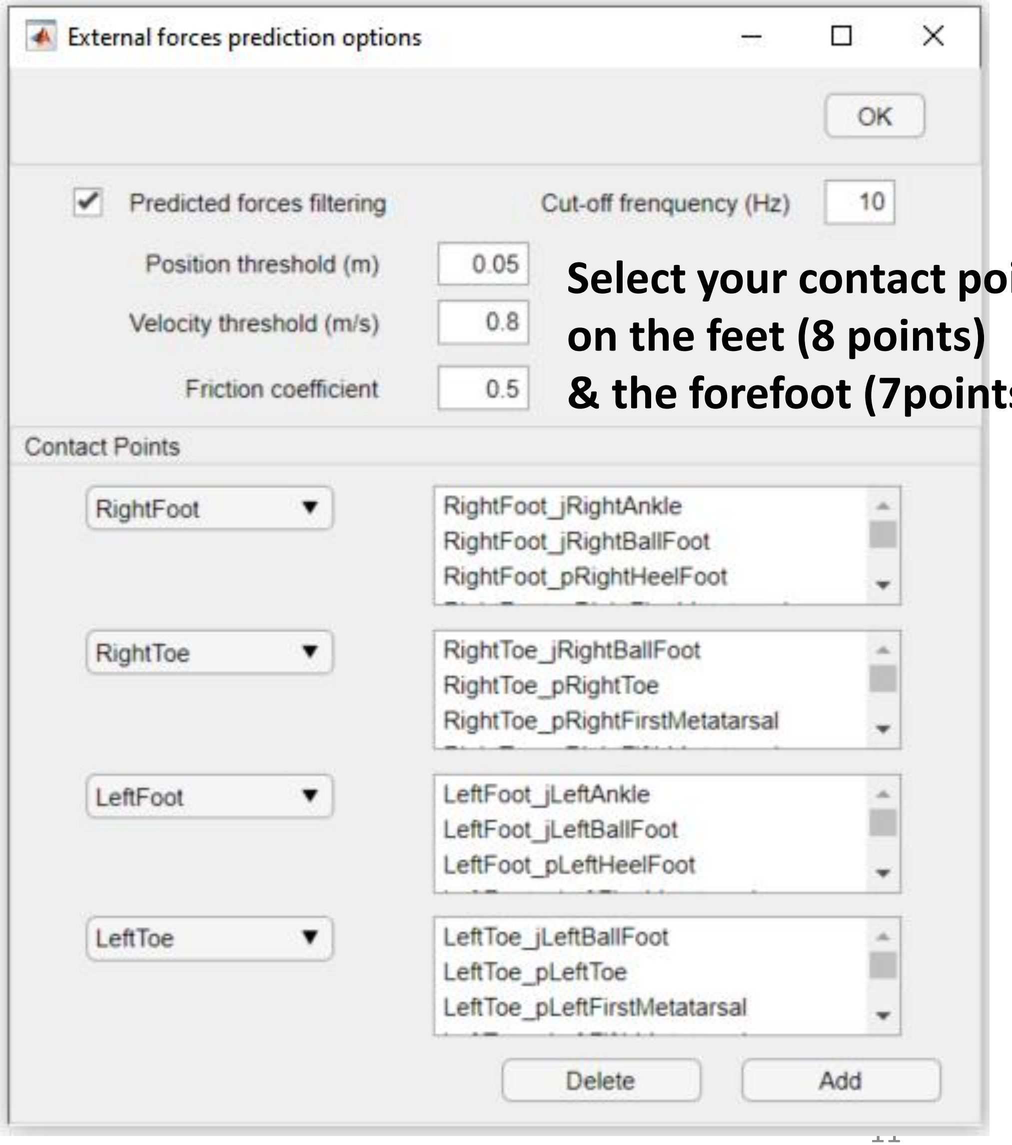
Select your trial

Given by XSENS

Generate AnalysisParameters

- Open Options
- Add contact points: « Rfoot » and select all the « RfootPrediction » points
- Add contact points: « RightToe » and select all the « RightToe Prediction » points
- Add contact points: « Lfoot » and select all the « LfootPrediction » points
- Add contact points: « LeftToe » and select all the « RfootPrediction » points

Use Crtl+Click or Shift+Click to select multiple points



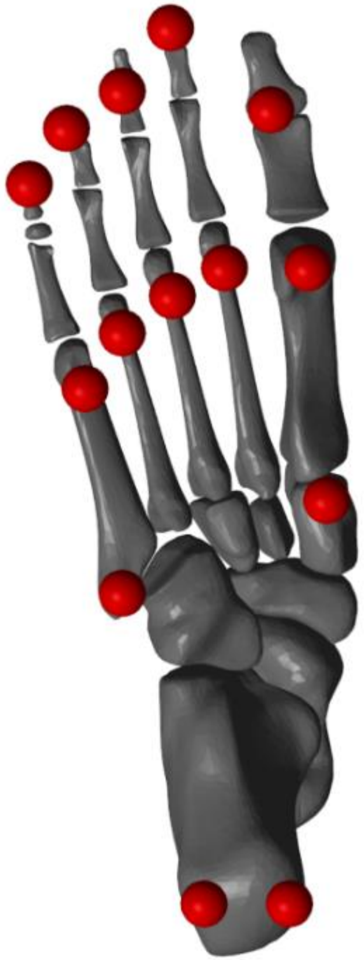
Select your contact points on the feet (8 points) & the forefoot (7points)

RUN

```
External Forces Prediction (ChgtDirection04) ...
... External Forces Prediction (ChgtDirection04) done
Inverse dynamics (ChgtDirection04) ...
... Inverse dynamics (ChgtDirection04) done
Forces Computation (ChgtDirection04) ...
... Forces Computation (ChgtDirection04) done
```

new

What are the points ?



Anatomical points defined on the feet as contact points

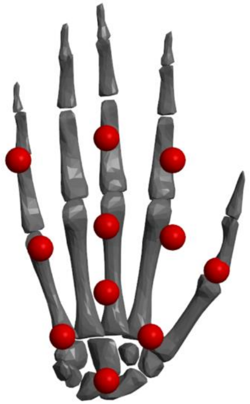
See **…\Functions\Models\Osteoarticular\Leg\ModelParts\foot.m**

R. Fluit, M. S. Andersen, S. Kolk, N. Verdonschot, and H. F. Koopman, “Prediction of ground reaction forces and moments during various activities of daily living,” Journal of biomechanics vol. 47, no. 10, pp. 2321–2329, 2014

S. Skals, M. K. Jung, M. Damsgaard, and M. S. Andersen,
“Prediction of ground reaction forces and moments during sports-related movements,” Multibody system dynamics, vol. 39, no. 3,pp. 175–195, 2017

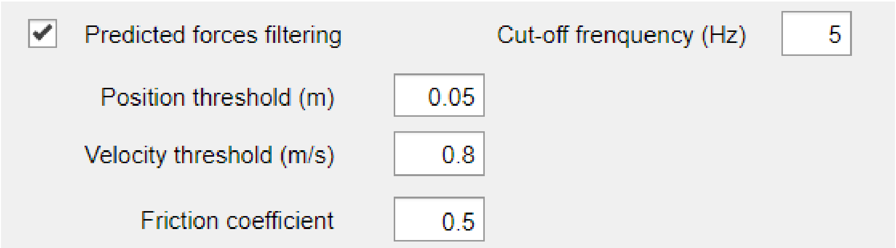
Muller A., Pontonnier C., Dumont G. Motion-based prediction of hands and feet contact efforts during asymmetric handling tasks, in review

You can add contact points on any segment of the model !

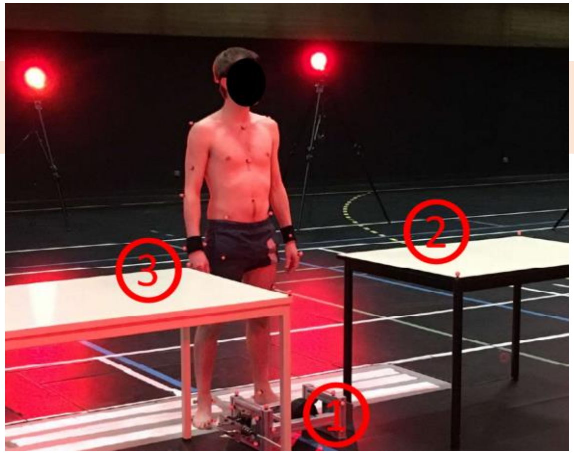


What are the tresholds ?

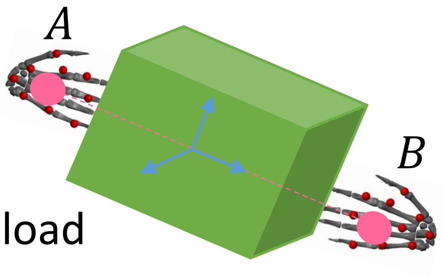
Contact is allowed (force is allowed to be generated on the considered point) if thresholds are reached and maximal force per point is constrained to 0.4 BW. Coulombs law links normal and tangential components of the force



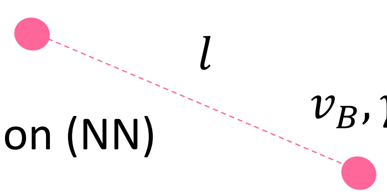
Motion-based external forces prediction



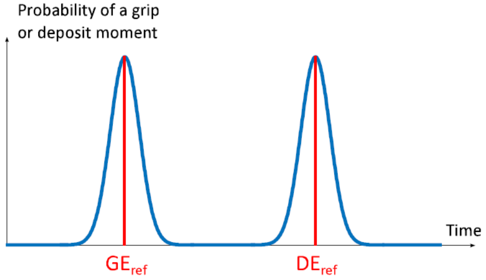
Handling tasks

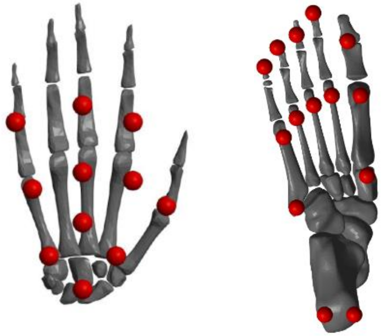


Marker-based motion reconstruction of the load



Grip/deposit event detection (NN)



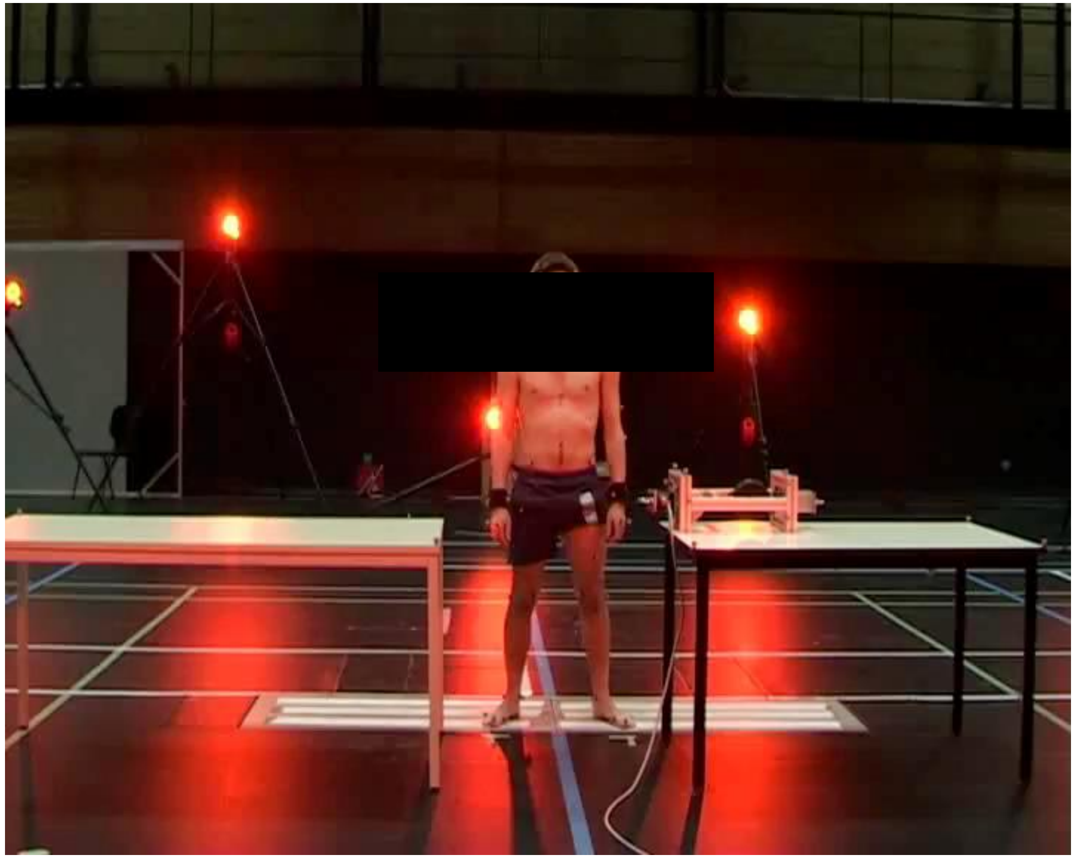


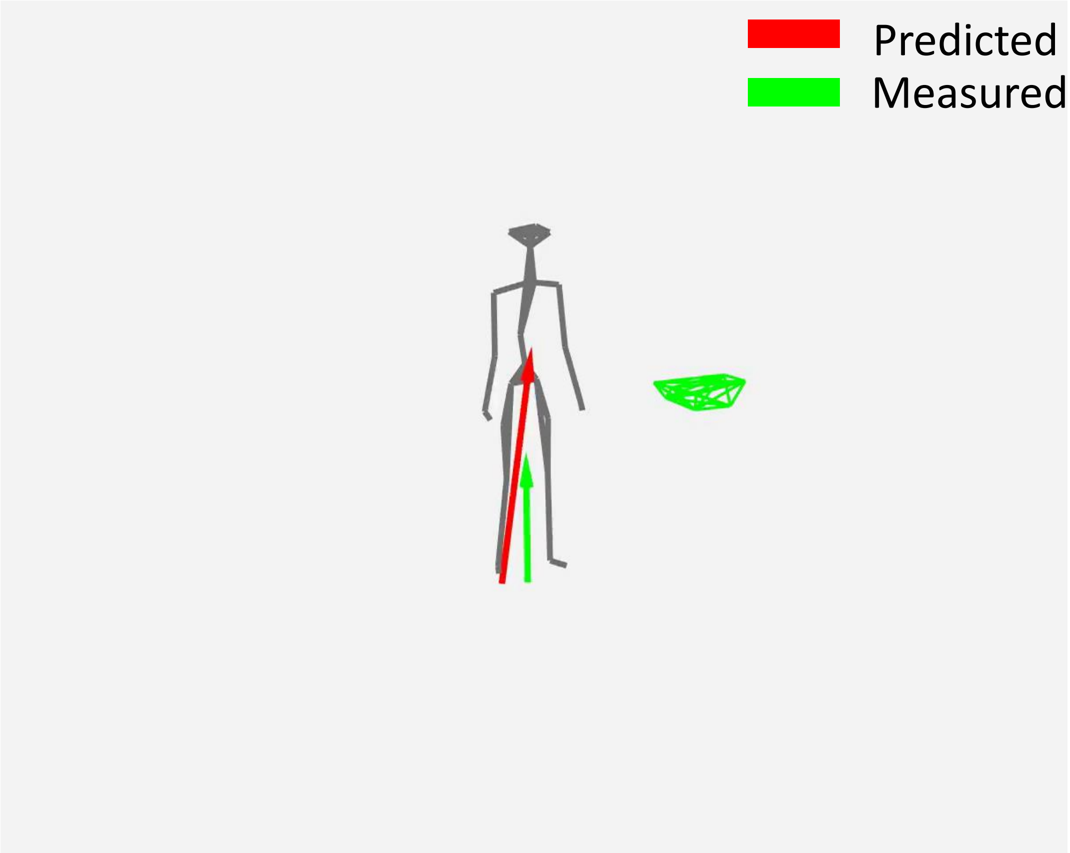
Contact zones mapping

$$\min_{F} \sum_{i=1}^{2N_f} \|\boldsymbol{F_i}\|^2$$

$$s.t. \begin{cases} M_s(\boldsymbol{q})\ddot{\boldsymbol{q}} + C_s(\boldsymbol{q}, \dot{\boldsymbol{q}}) + G_s(\boldsymbol{q}) + \boldsymbol{E_s} = \boldsymbol{0} \\ M_l(\boldsymbol{q})\ddot{\boldsymbol{q}} + C_l(\boldsymbol{q}, \dot{\boldsymbol{q}}) + G_l(\boldsymbol{q}) + \boldsymbol{E_l} = \boldsymbol{0} \\ \forall i \in [1, 2(N_f + N_h)], \boldsymbol{F_i} < \boldsymbol{F_{i_{max}}} \end{cases}$$

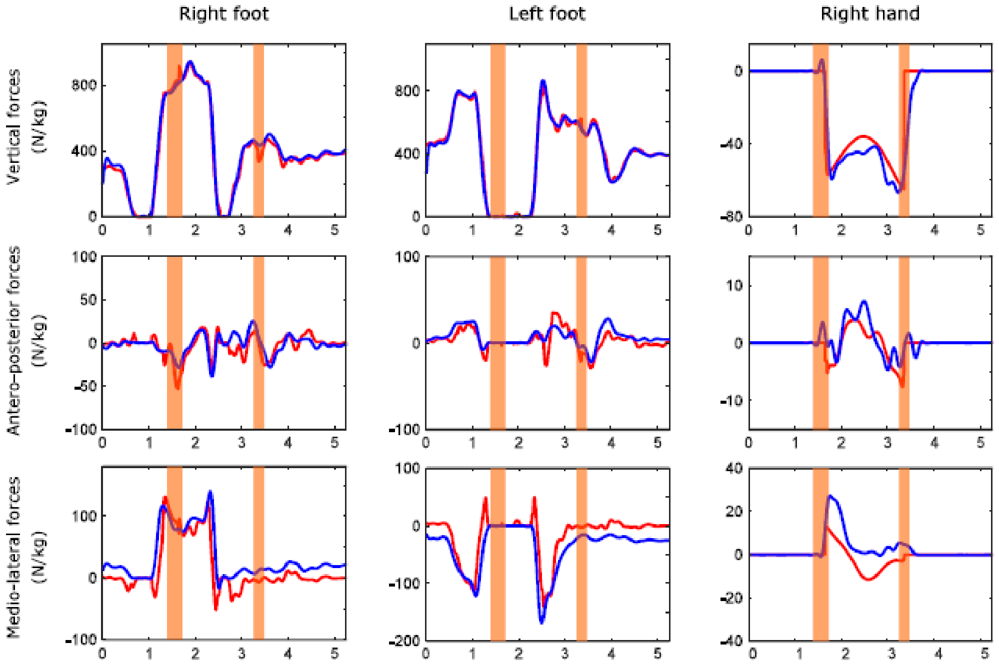
Measuring





Measuring

Motion-based external forces prediction



Fine for vertical forces ~2.5% RMSE

Ok for antero-posterior forces ~15% RMSE

Bad for medio-lateral forces ~40% RMSE

Contact parameters ?

Internal torques ?

Contact points ?

Good enough to predict forces for standardized tasks (not much variability in the handling)

What CusToM is doing ?

$$\min_{(\boldsymbol{\alpha},\boldsymbol{\beta},\boldsymbol{\gamma})} \sum_{i=1}^{2N_f} (\alpha_i^2 + \beta_i^2 + \gamma_i^2)$$

$$\text{s.t.} \quad \boxed{\boldsymbol{M_s}(\boldsymbol{q})\ddot{\boldsymbol{q}} + \boldsymbol{C_s}(\boldsymbol{q},\dot{\boldsymbol{q}}) + \boldsymbol{G_s}(\boldsymbol{q}) + \boldsymbol{\lambda_s} + \boldsymbol{E_s} = \boldsymbol{0};}$$

$$\forall i \in [\![1, 2N_f]\!], (\alpha_i, \beta_i, \gamma_i) \in [-1, 1]^3$$

Equations of motion
(Newton-Euler and sum at pelvis)

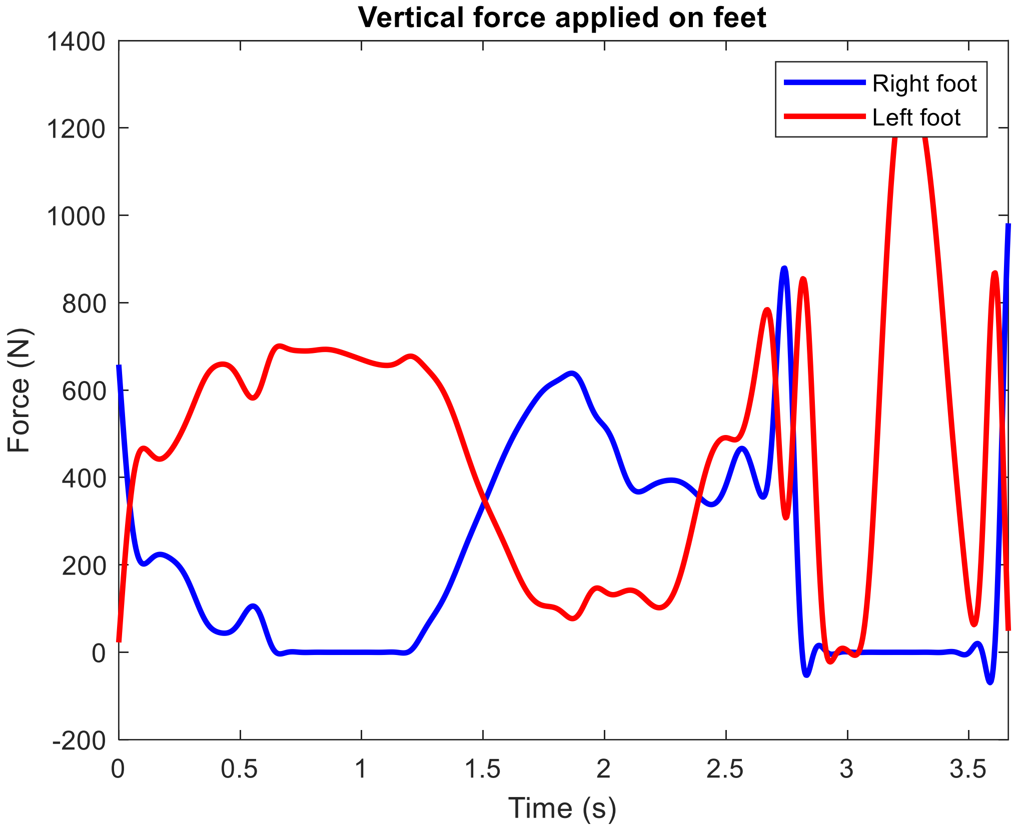
$$\boxed{\boldsymbol{F_i} = \alpha_i\, F_{i,x}^{max}\, \boldsymbol{x} + \beta_i\, F_{i,y}^{max}\, \boldsymbol{y} + \gamma_i\, F_{i,z}^{max}\, \boldsymbol{z}}$$

Each contact point has a minimal contribution to the global equilibrium

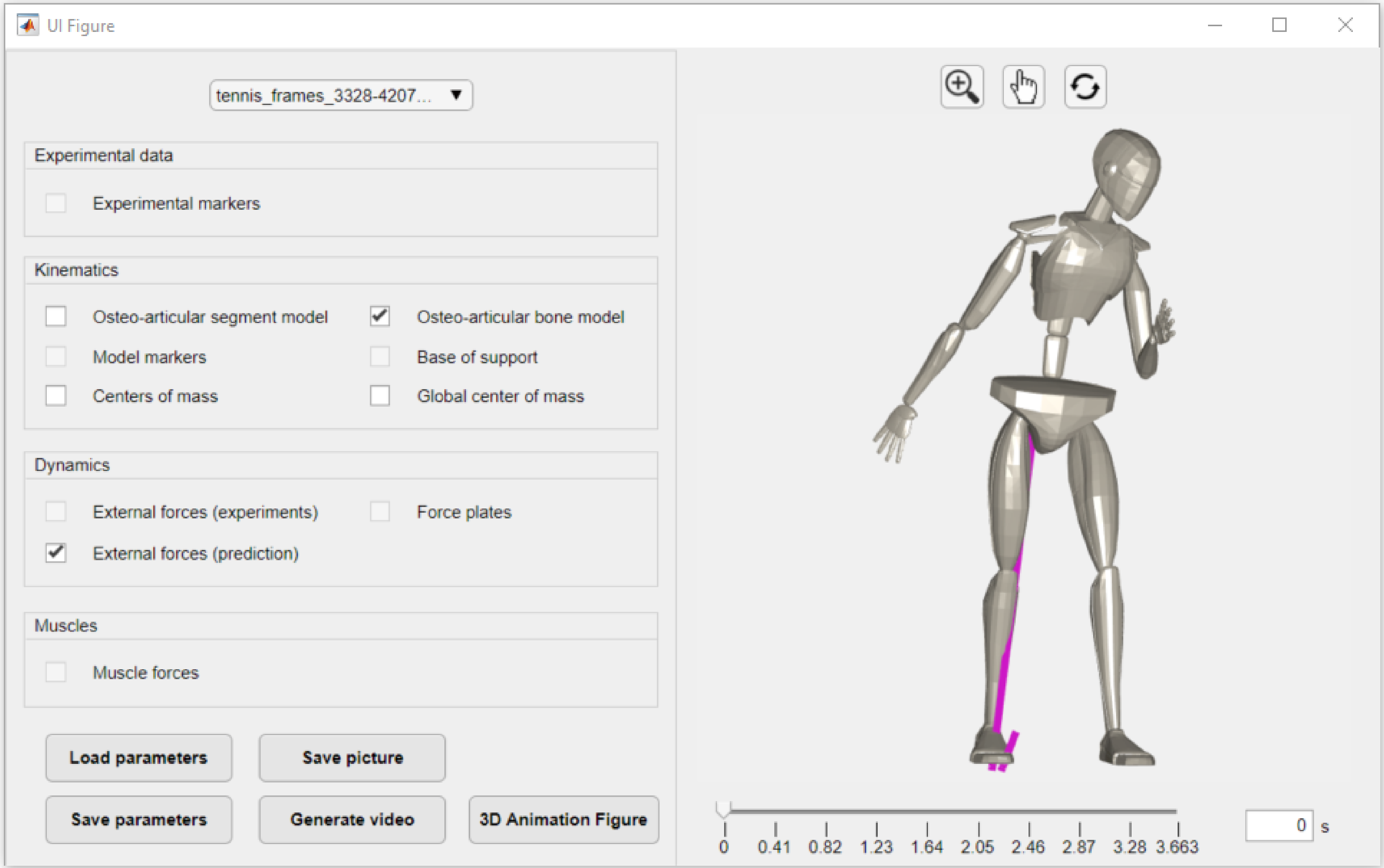
Postprocessing

Run The analysis

And the postProcessing to visualize the predicted ground reaction forces



Animation



UI Figure
tennis_frames_3328-4207...
Experimental data
Experimental markers
Kinematics
Osteo-articular segment model
Osteo-articular bone model
Model markers
Base of support
Centers of mass
Global center of mass
Dynamics
External forces (experiments)
Force plates
External forces (prediction)
Muscles
Muscle forces
Load parameters
Save picture
Save parameters
Generate video
3D Animation Figure
0
0.41
0.82
1.23
1.64
2.05
2.46
2.87
3.28
3.663
0
s

Video