CusToM Workshop

Kinematic tutorial

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20/12/2019

Pre-Work

Go in `Examples\1_Walking\POC0980A_normal_Anthropo`

It contains :

Marche.c3d	16/12/2019 11:28	Fichier C3D
PostProcessingKinematic_Anthropo.m	16/12/2019 11:52	MATLAB Code

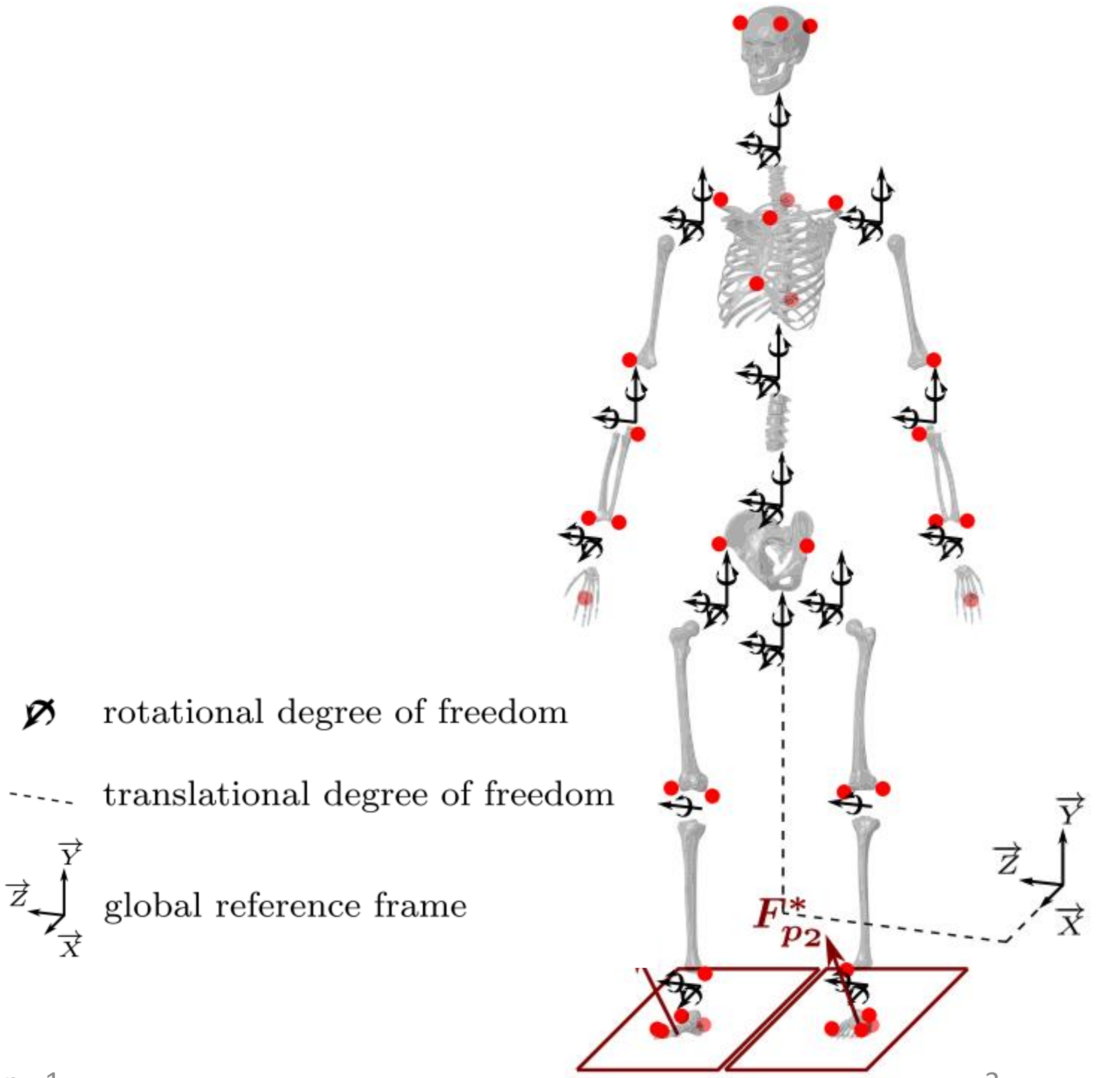
Generate Parameters of the Model

```
>> GenerateParameters
```

- Size : 1.74 m
- Mass : 64 Kg

- Osteo-articular model – full body
  - Pelvis
  - Pelvis LowerTrunk
  - Leg
  - Arms
- Marker Set
  - MarkerSet_2 (M2S makerset)
  - 1 markers on hand

- Lower Limb muscles



AnalysisParameters

Only Inverse Kinematic Active Step

- Levenberg-marquardt
- 5Hz filter butterworh 2nd order zero lag

What CusToM is Doing ?

```
Anthropometric Model Generation ...
... Anthropometric Model Generation done
```

The osteoarticular model comes from cadaveric data.

Anthropometric scaling:

- Segments lengths
- Anatomical landmarks

$$k_0 = \frac{size\ of\ the\ subject}{size\ of\ the\ cadaver}$$

What CusToM is Doing ?

```
Preliminary Computations ...
... Preliminary Computations done
```

A priori known location of anatomical landmarks are computed in the global reference frame R_0 function of joint coordinates $\boldsymbol{q}$

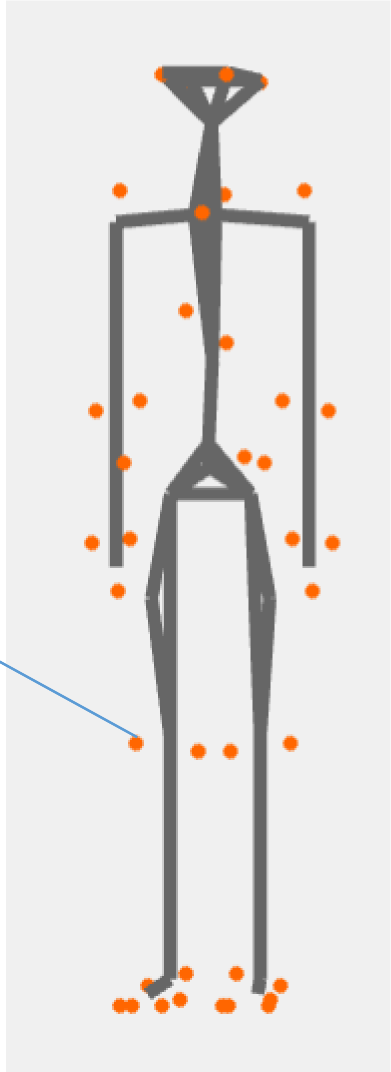
$$^{R_0}\boldsymbol{X}_{\boldsymbol{marker}} = f(\boldsymbol{q})$$

Jacobian matrix $\boldsymbol{J}$ are computed analytically

- For Inverse kinematics using Levenberg-Marquardt algorithms

$$\boldsymbol{J} = \boldsymbol{J}_{\boldsymbol{f},\boldsymbol{q}} + \boldsymbol{J}_{\boldsymbol{f},\boldsymbol{cut}} * (\boldsymbol{J}_{\boldsymbol{cut},\boldsymbol{cut}} * \boldsymbol{J}_{\boldsymbol{cut},\boldsymbol{q}})$$

$$\boldsymbol{J}_{\boldsymbol{f},\boldsymbol{q}}$$
$$\boldsymbol{J}_{\boldsymbol{f},\boldsymbol{cut}}$$
$$\boldsymbol{J}_{\boldsymbol{cut},\boldsymbol{q}}$$
$$\boldsymbol{J}_{\boldsymbol{cut},\boldsymbol{cut}}$$



What CusToM is Doing ?

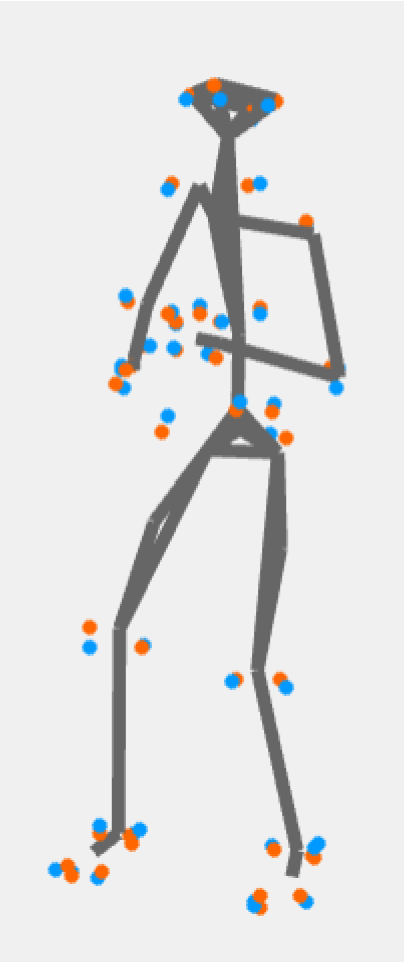
```
Inverse kinematics (ChgtDirection04) ...
... Inverse kinematics (ChgtDirection04) done
```

Euclidian distance minization between experimental markers ${}^{R_0}\boldsymbol{X}_{exp,i}$ and *a priori* know location of anatomical landmarks ${}^{R_0}\boldsymbol{X}_{mod,m}(\boldsymbol{q})$ in the global frame R_0

$$\min_{\boldsymbol{q}} \sum_{i}^{N_{markers}} \left\| {}^{R_0}\boldsymbol{X}_{exp,i} - {}^{R_0}\boldsymbol{X}_{mod,m}(\boldsymbol{q}) \right\|^2$$

We get the joint coordinates $\boldsymbol{q}$.

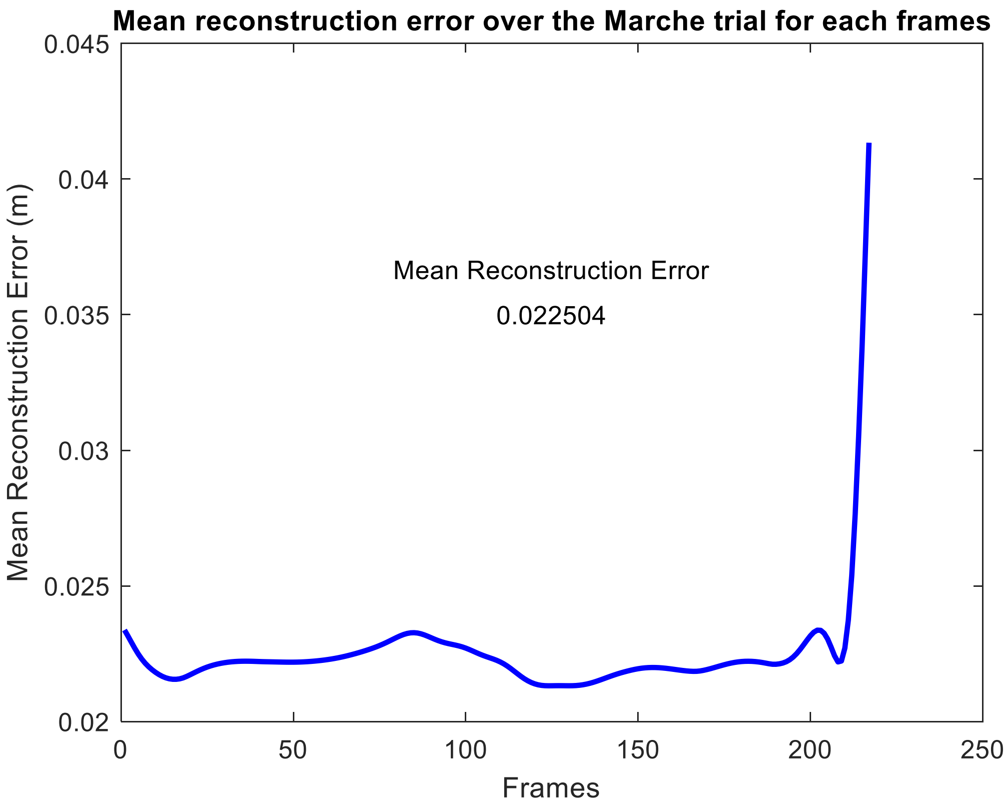
Levenberg-marquardt : $\left(\boldsymbol{J}^T\boldsymbol{J} + \lambda.diag(\boldsymbol{J}^T\boldsymbol{J})\right)\boldsymbol{\Delta q} = \boldsymbol{J}^T(\boldsymbol{X_{exp}} - \boldsymbol{X_{mod}}(\boldsymbol{q}))$

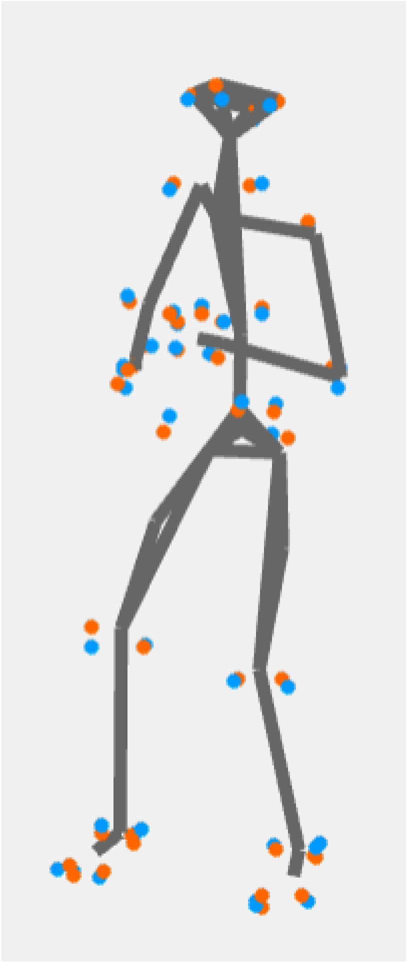


More details in Muller, A., 2017. Contributions méthodologiques à l'analyse musculo-squelettique de l'humain dans l'objectif d'un compromis précision performance. École normale supérieure de Rennes.

First results – Kinematic residuals

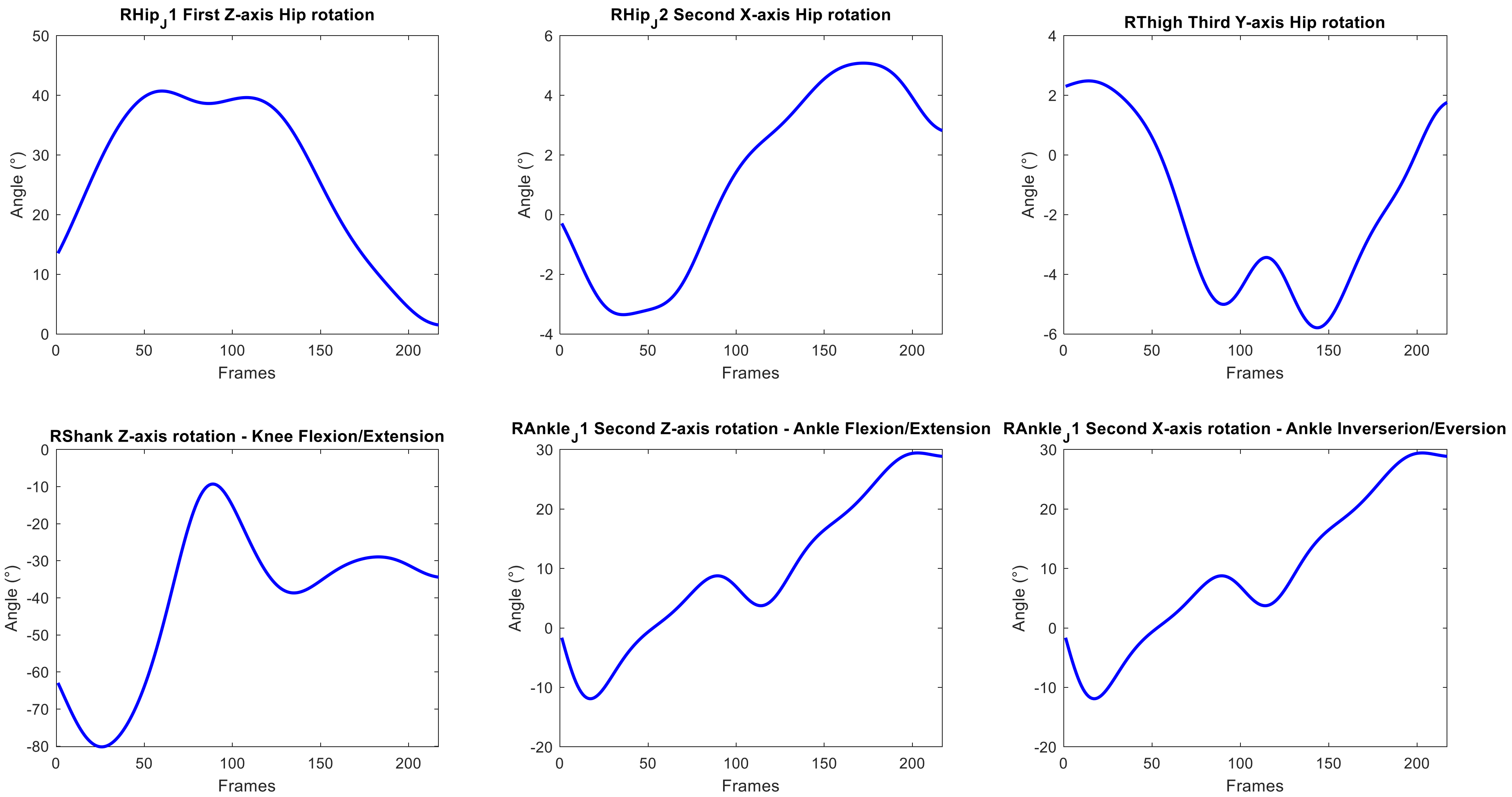
```
>> PostProcessingKinematic_Anthropo
```

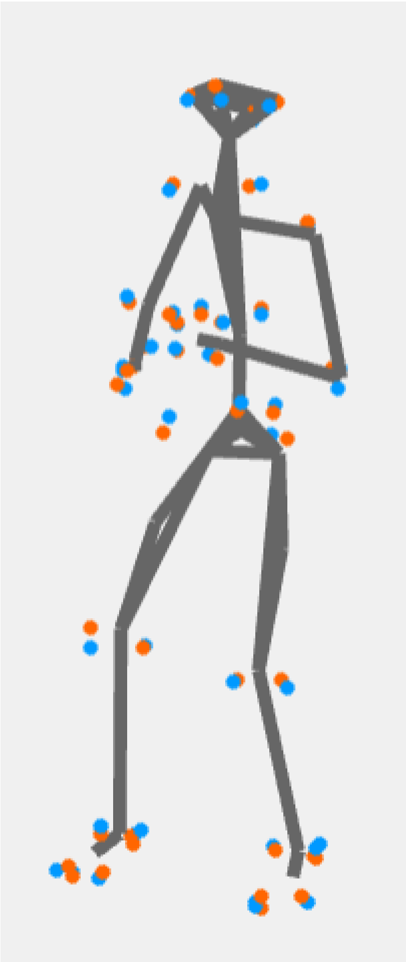




First results – Joint coordinates

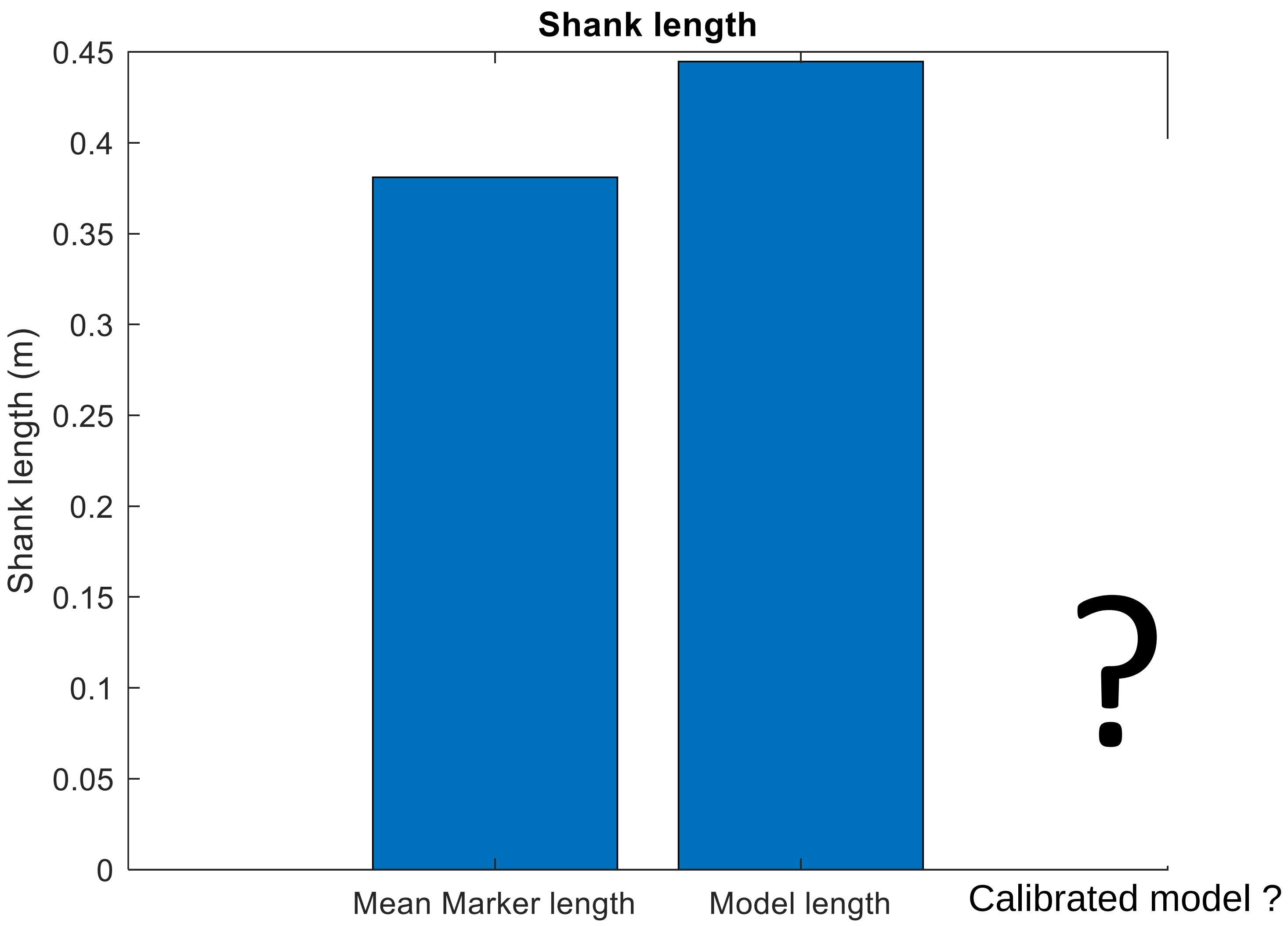
```
>> PostProcessingKinematic_Anthropo
```

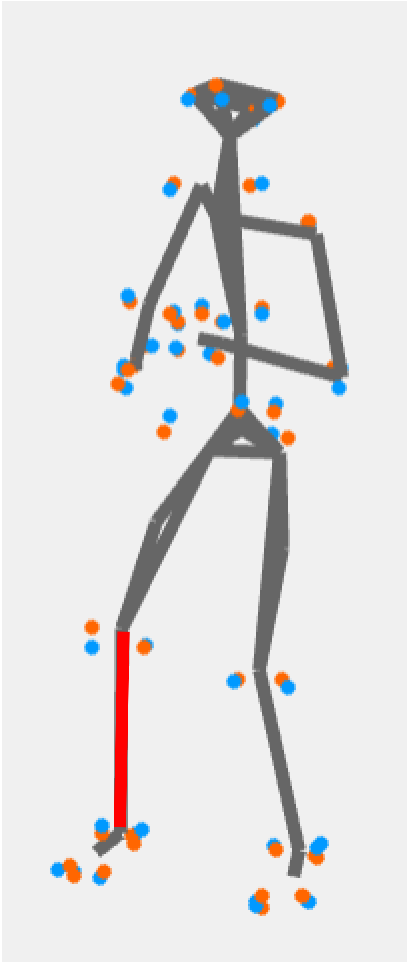




What about the quality of the model ? – Right Shank length

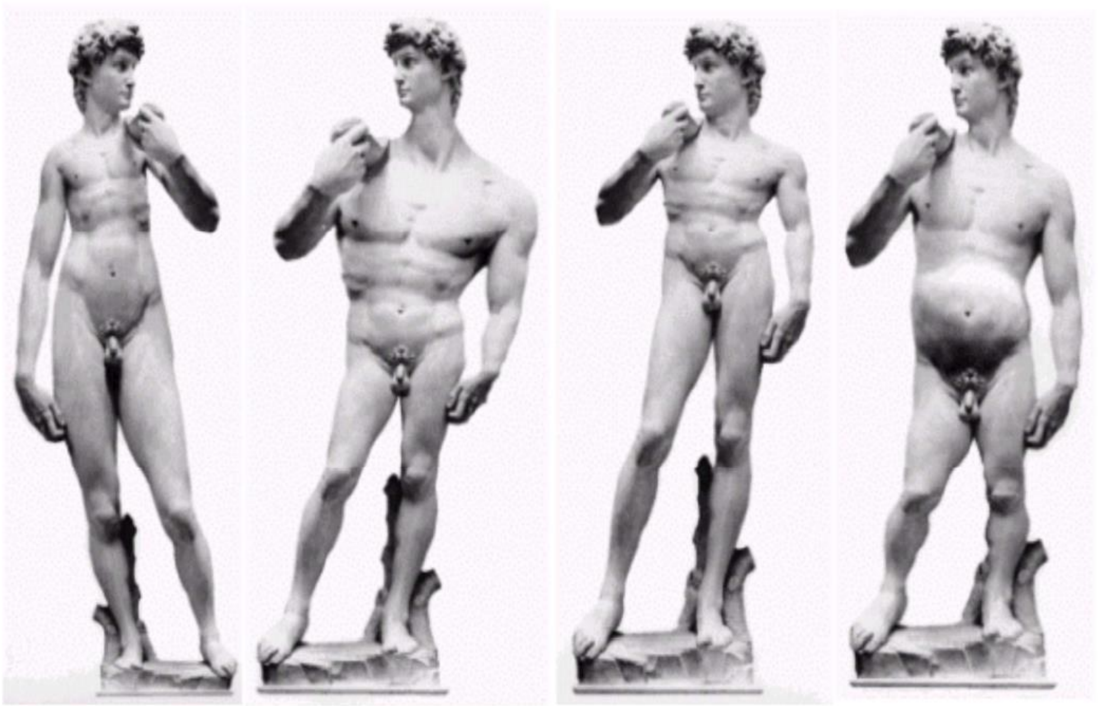
```
>> PostProcessingKinematic_Anthropo
```





What about the quality of the model ?

For a same size, segment lengths can vary between subjects.



Pre-Work

Go in `Examples\1_Walking\POC0980A_normal_Geometric_Calibration`

It contains :

Marche.c3d	16/12/2019 11:28	Fichier C3D
PostProcessingCalibration.m	28/11/2018 18:20	MATLAB Code
PostProcessingKinematic_Calibration.m	16/12/2019 14:02	MATLAB Code
PostProcessingShankLength.m	28/11/2018 21:58	MATLAB Code
ROM01.c3d	30/01/2019 09:38	Fichier C3D

We will add a geometric calibration step

Same previous steps, except for AnalysisParameters.

Geometrical Calibration step

- Frames used
  - Selection method of frames : **UniformlyDistributed**
  - Number of frames **: 20**

- Body length
  - Homethetic factors of Clavicles are linked to homothetic factor of the Thorax

- Marker Position
  - Direction of markers to optimize in local frames (Z is medio-lateral)

- Axis of rotation
  - Orientation of Joint axis can be optimized to fit subject-specific joint axis.
  - For example knee axis. Two rotation angles have to be introduced.

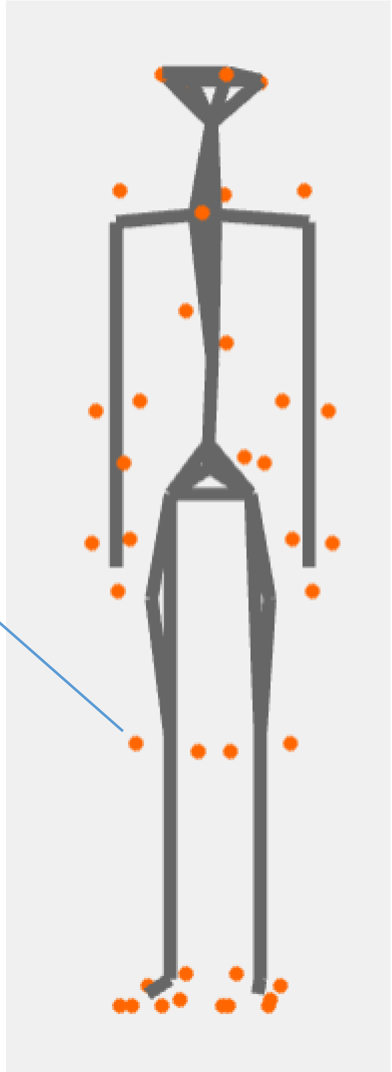
What is CusToM Doing ?

```
Geometrical Calibration ...
... Geometrical Calibration done
```

A priori known location of anatomical landmarks are computed in the global reference frame R_0,function of:

- joint coordinates $\boldsymbol{q}$,
- homothetic factors $\boldsymbol{k}$,
- variation of marker position $\Delta\boldsymbol{p}$,
- rotation of joint axis $\boldsymbol{\alpha}$.

$$^{R_0}\boldsymbol{X}_{\boldsymbol{marker}} = f(\boldsymbol{q}, \boldsymbol{k}, \Delta\boldsymbol{p}, \boldsymbol{\alpha})$$

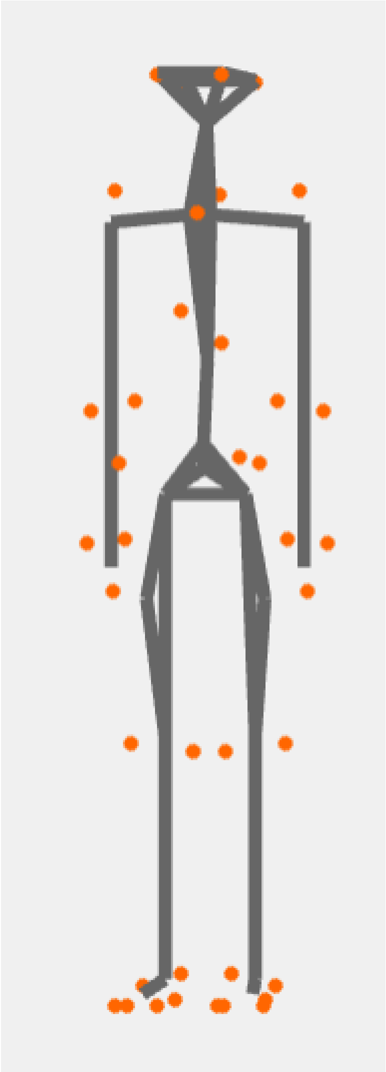


What is CusToM Doing ?

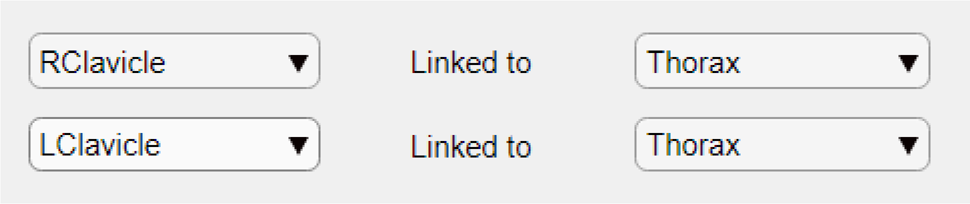
```
Geometrical Calibration ...
... Geometrical Calibration done
```

Uniformely distributed frames

Frames are chosen equally spaced in ROM.c3d



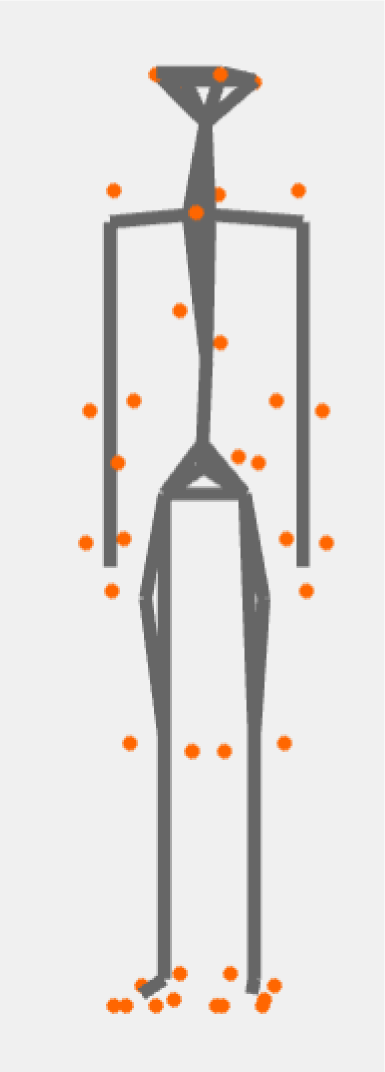
What is CusToM Doing ?



Body Length

Linear Constraints of homothetic factors.

$$\begin{cases} k_{R_{Clavicle}} - k_{Thorax} = 0 \\ k_{L_{Clavicle}} - k_{Thorax} = 0 \end{cases}$$

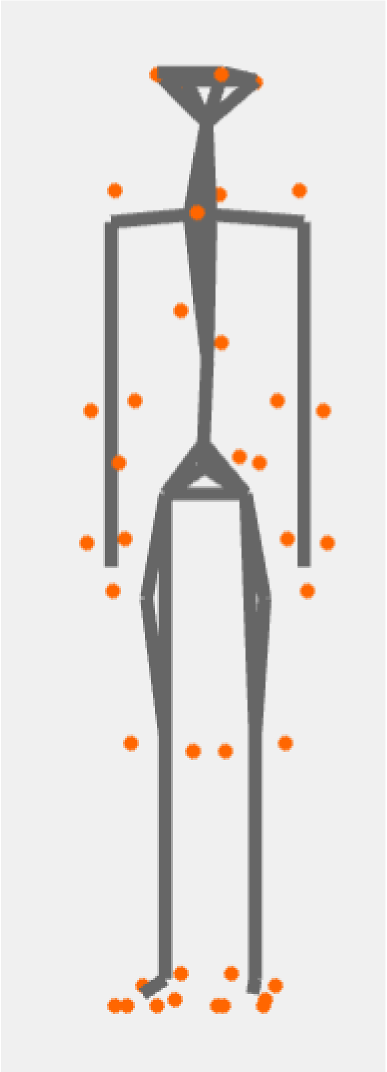


What is CusToM Doing ?

```
Geometrical Calibration ...
... Geometrical Calibration done
```

Axis of rotation

$$^{R_i}\boldsymbol{X}_{\boldsymbol{marker}} = {}^{R_i}\boldsymbol{p}_A + {}^{R_i}\Delta\boldsymbol{p}$$



What is CusToM Doing ?

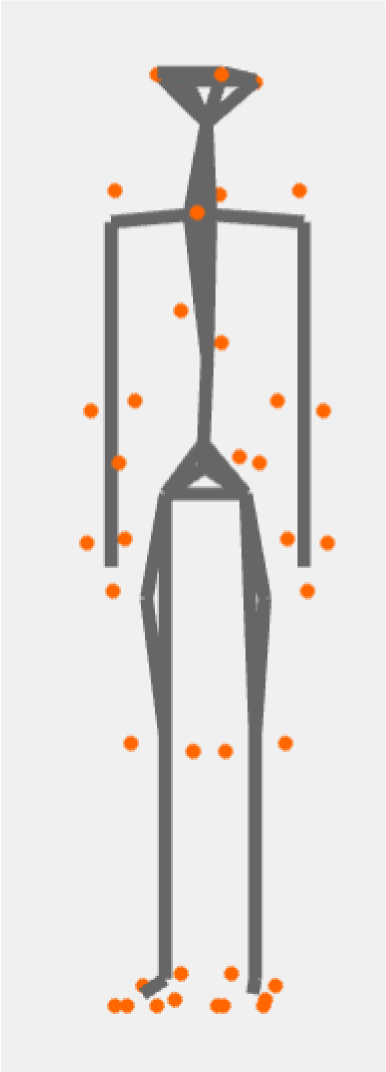
```
Geometrical Calibration ...
... Geometrical Calibration done
```

Axis of rotation

$$^{R_i}\boldsymbol{X}_{\boldsymbol{marker}} = {}^{R_i}\boldsymbol{p}_A + {}^{R_i}\Delta\boldsymbol{p}$$

Some location of markers are optimized

In this case :



What is CusToM Doing ?

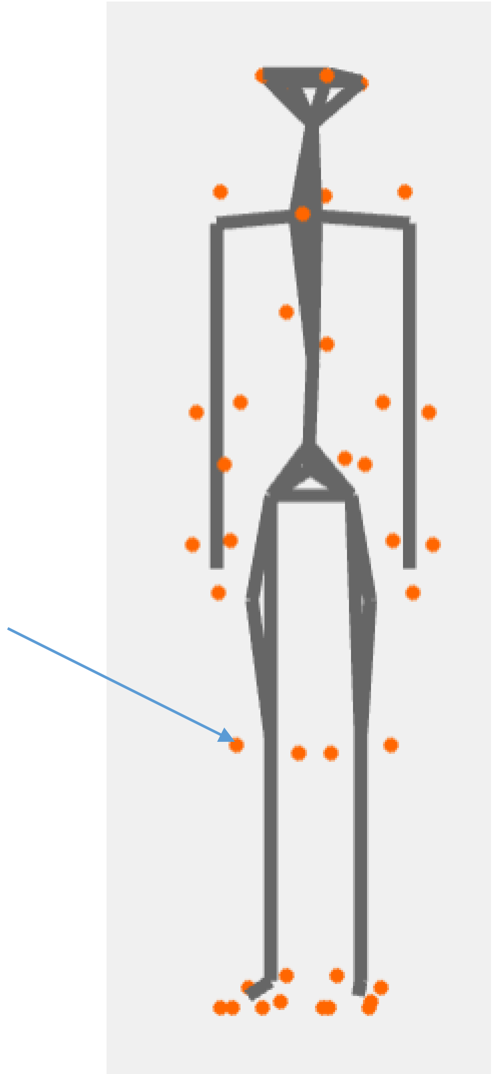
```
Geometrical Calibration ...
... Geometrical Calibration done
```

Axis of rotation

$$^{R_i}\boldsymbol{X}_{\boldsymbol{marker}} = {}^{R_i}\boldsymbol{p}_A + {}^{R_i}\Delta\boldsymbol{p}$$

Some location of markers are optimized

In this case :



What is CusToM Doing ?

```
Geometrical Calibration ...
... Geometrical Calibration done
```

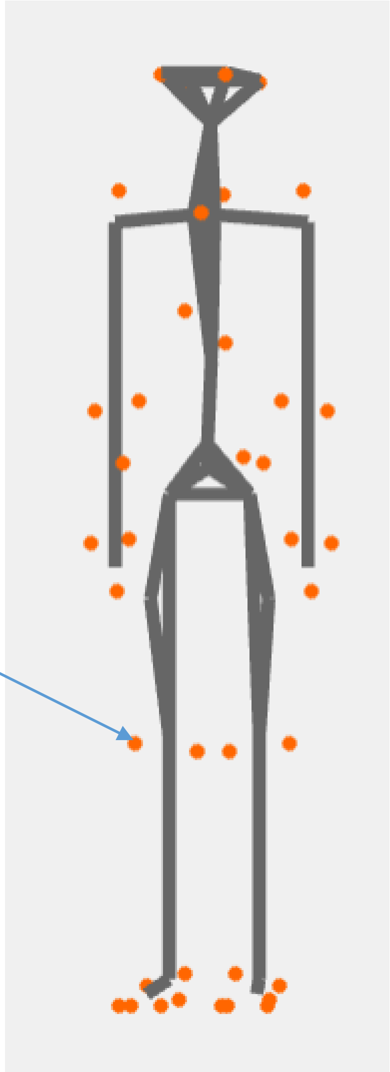
Axis of rotation

$$^{R_i}\boldsymbol{X}_{\boldsymbol{marker}} = {}^{R_i}\boldsymbol{p}_A + {}^{R_i}\Delta\boldsymbol{p}$$

Some location of markers are optimized

In this case :

RKNE



What is CusToM Doing ?

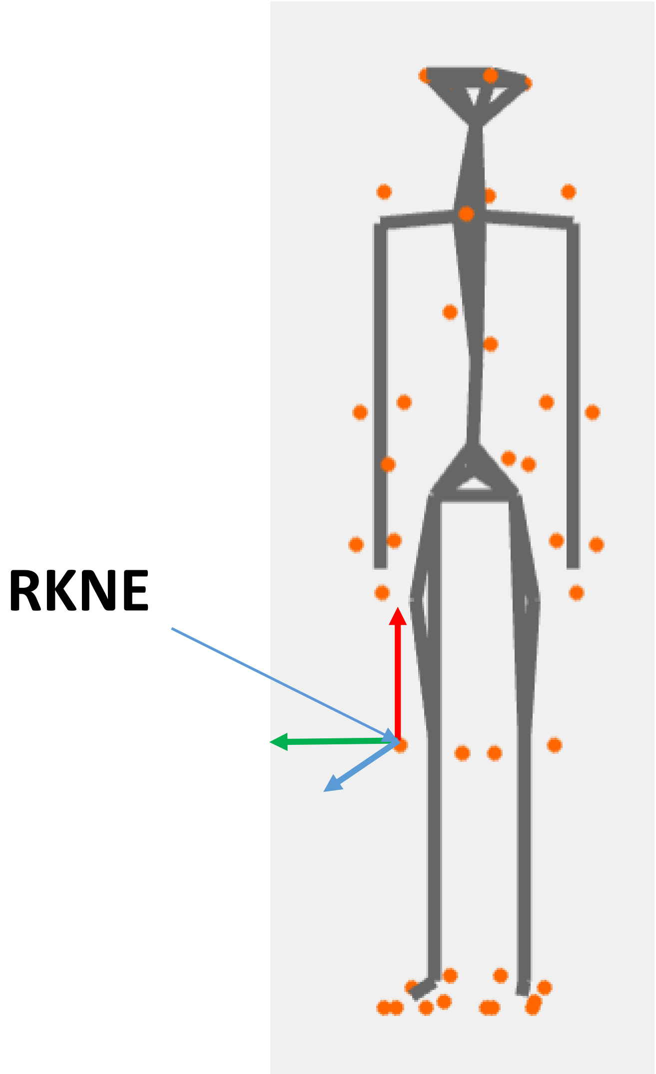
```
Geometrical Calibration ...
... Geometrical Calibration done
```

Axis of rotation

$$^{R_i}\boldsymbol{X}_{\boldsymbol{marker}} = {}^{R_i}\boldsymbol{p}_A + {}^{R_i}\Delta\boldsymbol{p}$$

Some location of markers are optimized

In this case :



What is CusToM Doing ?

```
Geometrical Calibration ...
... Geometrical Calibration done
```

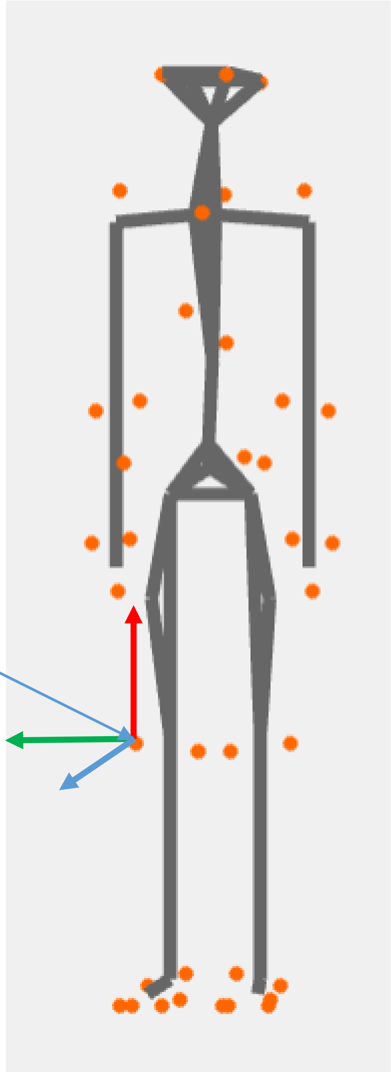
Axis of rotation

$$^{R_i}\boldsymbol{X}_{\boldsymbol{marker}} = {}^{R_i}\boldsymbol{p}_A + {}^{R_i}\Delta\boldsymbol{p}$$

Some location of markers are optimized

In this case :

RKNE



What is CusToM Doing ?

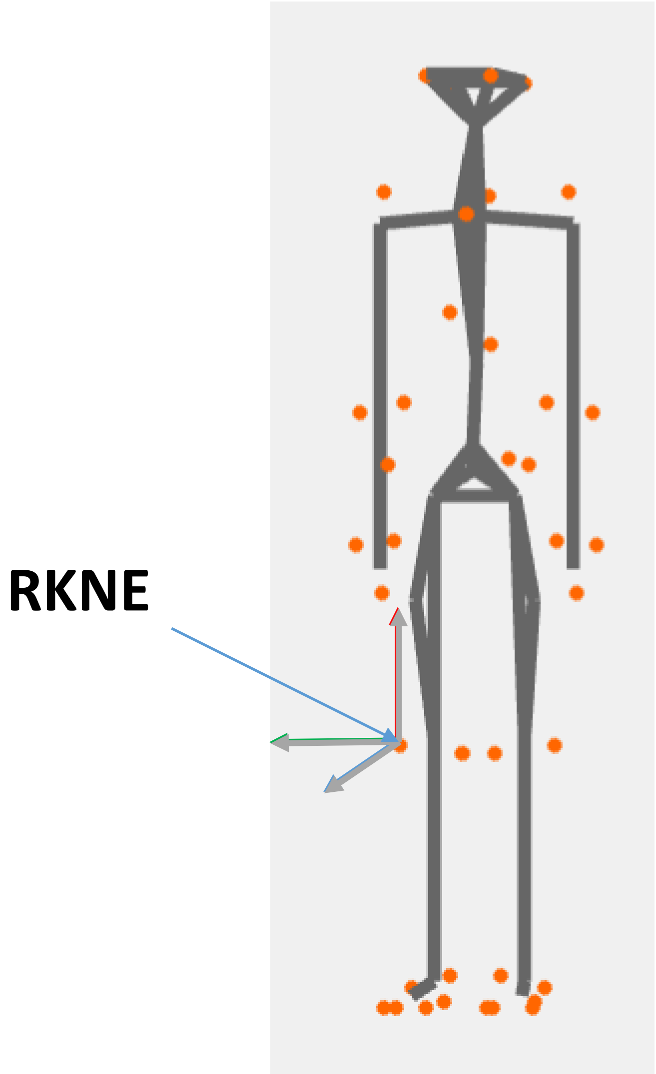
```
Geometrical Calibration ...
... Geometrical Calibration done
```

Axis of rotation

$$^{R_i}\boldsymbol{X}_{\boldsymbol{marker}} = {}^{R_i}\boldsymbol{p}_A + {}^{R_i}\Delta\boldsymbol{p}$$

Some location of markers are optimized

In this case :



What is CusToM Doing ?

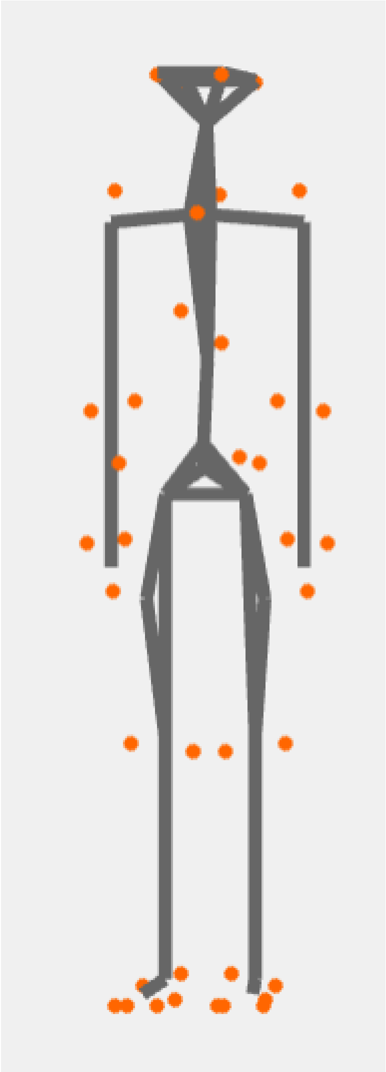
```
Geometrical Calibration ...
... Geometrical Calibration done
```

Axis of rotation

$$ {}^{R_i}\boldsymbol{X}_{\boldsymbol{marker}} = {}^{R_i}\boldsymbol{p}_A + {}^{R_i}\Delta\boldsymbol{p} $$

Some location of markers are optimized

In this case :



What is CusToM Doing ?

```
Geometrical Calibration ...
... Geometrical Calibration done
```

Axis of rotation

$$^{R_i}\boldsymbol{X}_{\boldsymbol{marker}} = {}^{R_i}\boldsymbol{p}_A + {}^{R_i}\Delta\boldsymbol{p}$$

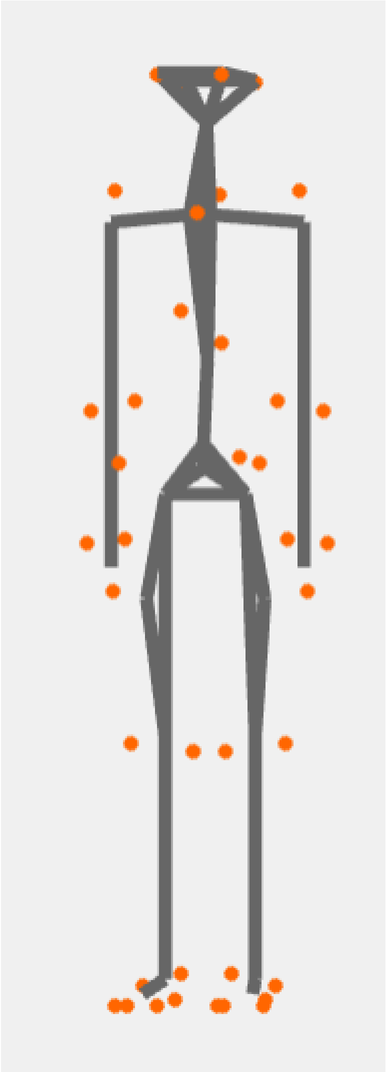
RKNE is trusted for x,y,z direction

Some location of markers are optimized

In this case :

•RKNE is trusted for x,y,z direction

RKNE ☐ ☐ ☐



What is CusToM Doing ?

```
Geometrical Calibration ...
... Geometrical Calibration done
```

Axis of rotation

$$^{R_i}\boldsymbol{X}_{\boldsymbol{marker}} = {}^{R_i}\boldsymbol{p}_A + {}^{R_i}\Delta\boldsymbol{p}$$

RKNE is trusted for x,y,z direction

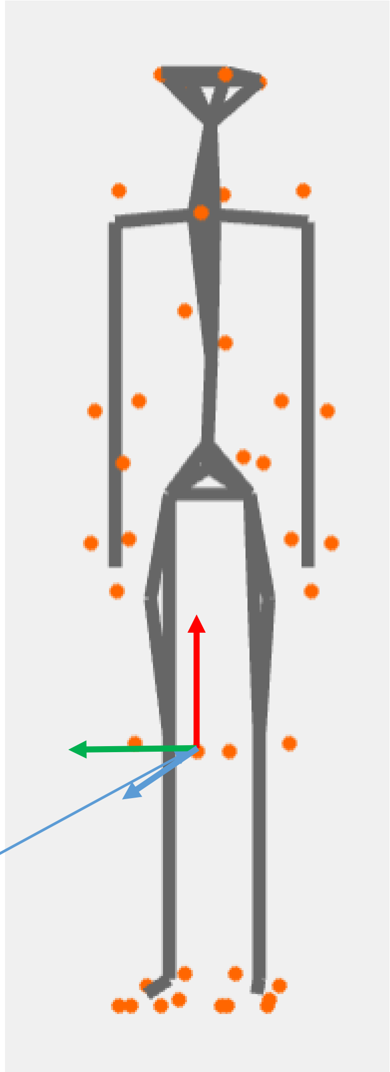
Some location of markers are optimized

In this case :

•RKNE is trusted for x,y,z direction

RKNE ☐ ☐ ☐

RKNI



What is CusToM Doing ?

```
Geometrical Calibration ...
... Geometrical Calibration done
```

Axis of rotation

$$ {}^{R_i}\boldsymbol{X}_{\boldsymbol{marker}} = {}^{R_i}\boldsymbol{p}_A + {}^{R_i}\Delta\boldsymbol{p} $$

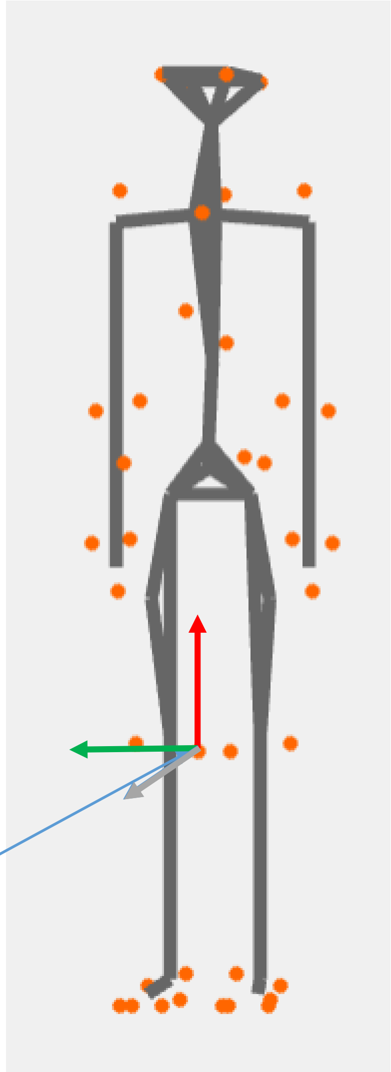
RKNE is trusted for x,y,z direction

Some location of markers are optimized

In this case :

•RKNE is trusted for x,y,z direction

RKNI



What is CusToM Doing ?

```
Geometrical Calibration ...
... Geometrical Calibration done
```

Axis of rotation

$$ {}^{R_i}\boldsymbol{X}_{\boldsymbol{marker}} = {}^{R_i}\boldsymbol{p}_A + {}^{R_i}\Delta\boldsymbol{p} $$

RKNE is trusted for x,y,z direction

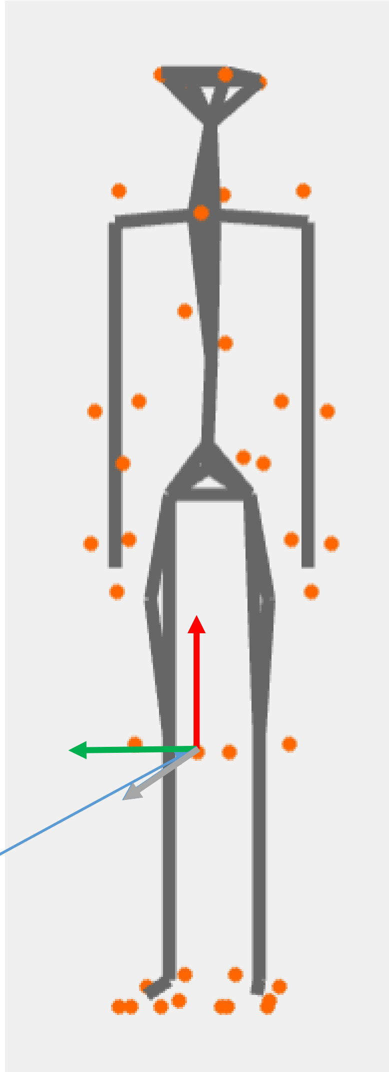
Some location of markers are optimized

In this case :

- RKNE is trusted for x,y,z direction

- RKNI is trusted for x direction and optimized for y and z direction

RKNI



What is CusToM Doing ?

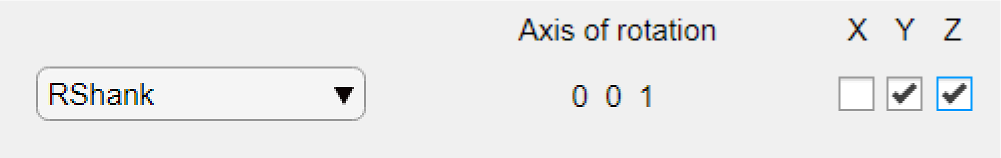
```
Geometrical Calibration ...
... Geometrical Calibration done
```

Axis of rotation

$$\overrightarrow{a_z}' = Rot(\alpha_1, \overrightarrow{a_x}) * \overrightarrow{a_0}$$

$$\overrightarrow{a_z}'' = Rot\left(\alpha_2, \overrightarrow{a_y}'\right) * \overrightarrow{a_z}'$$

$$\overrightarrow{a_z}'' = Rot\left(\alpha_2, \overrightarrow{a_y}'\right) * Rot(\alpha_1, \overrightarrow{a_x}) * \overrightarrow{a_0}$$



What is CusToM Doing ?

```
Geometrical Calibration ...
... Geometrical Calibration done
```

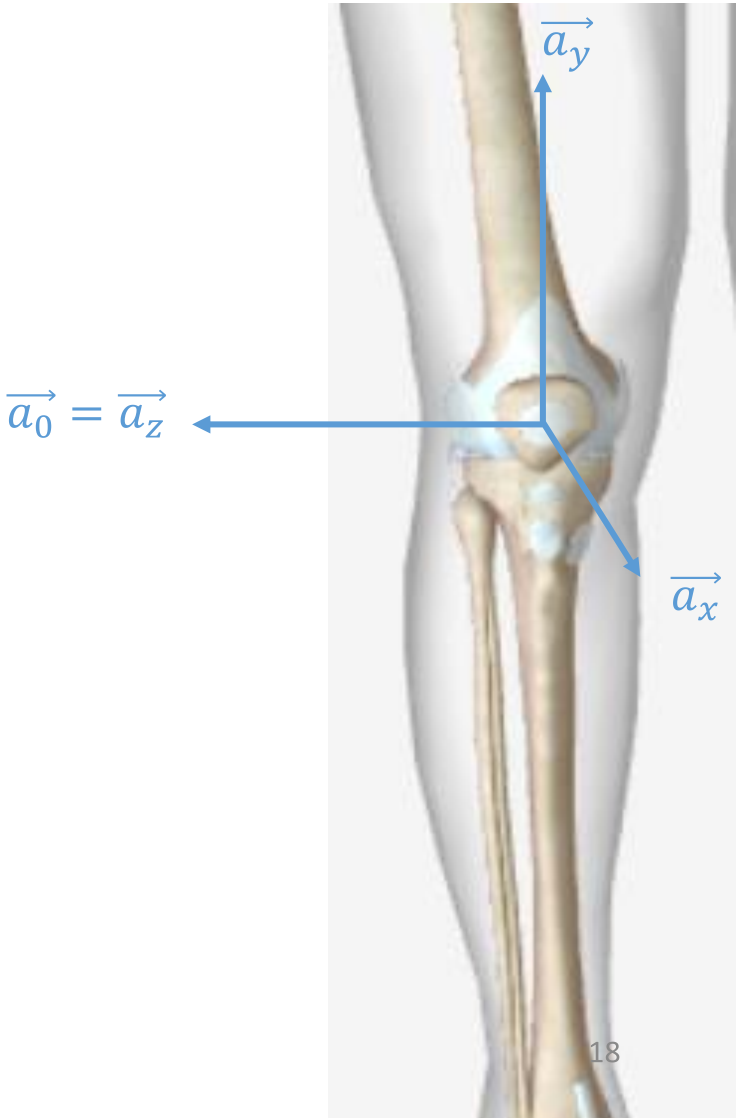
Axis of rotation

$$\overrightarrow{a_z}' = Rot(\alpha_1, \overrightarrow{a_x}) * \overrightarrow{a_0}$$

$$\overrightarrow{a_z}'' = Rot\left(\alpha_2, \overrightarrow{a_y}'\right) * \overrightarrow{a_z}'$$

$$\overrightarrow{a_z}'' = Rot\left(\alpha_2, \overrightarrow{a_y}'\right) * Rot(\alpha_1, \overrightarrow{a_x}) * \overrightarrow{a_0}$$

	Axis of rotation	X	Y	Z
RShank ▼	0 0 1	☐	☑	☑



What is CusToM Doing ?

```
Geometrical Calibration ...
... Geometrical Calibration done
```

Axis of rotation

$$\overrightarrow{a_z}' = Rot(\alpha_1, \overrightarrow{a_x}) * \overrightarrow{a_0}$$

$$\overrightarrow{a_z}'' = Rot\left(\alpha_2, \overrightarrow{a_y}'\right) * \overrightarrow{a_z}'$$

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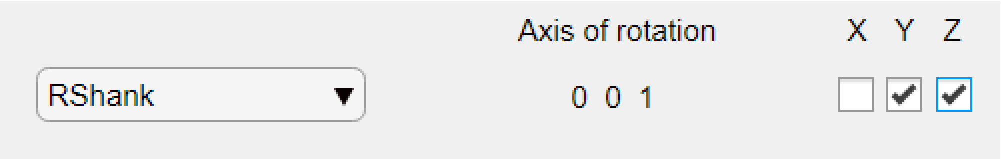
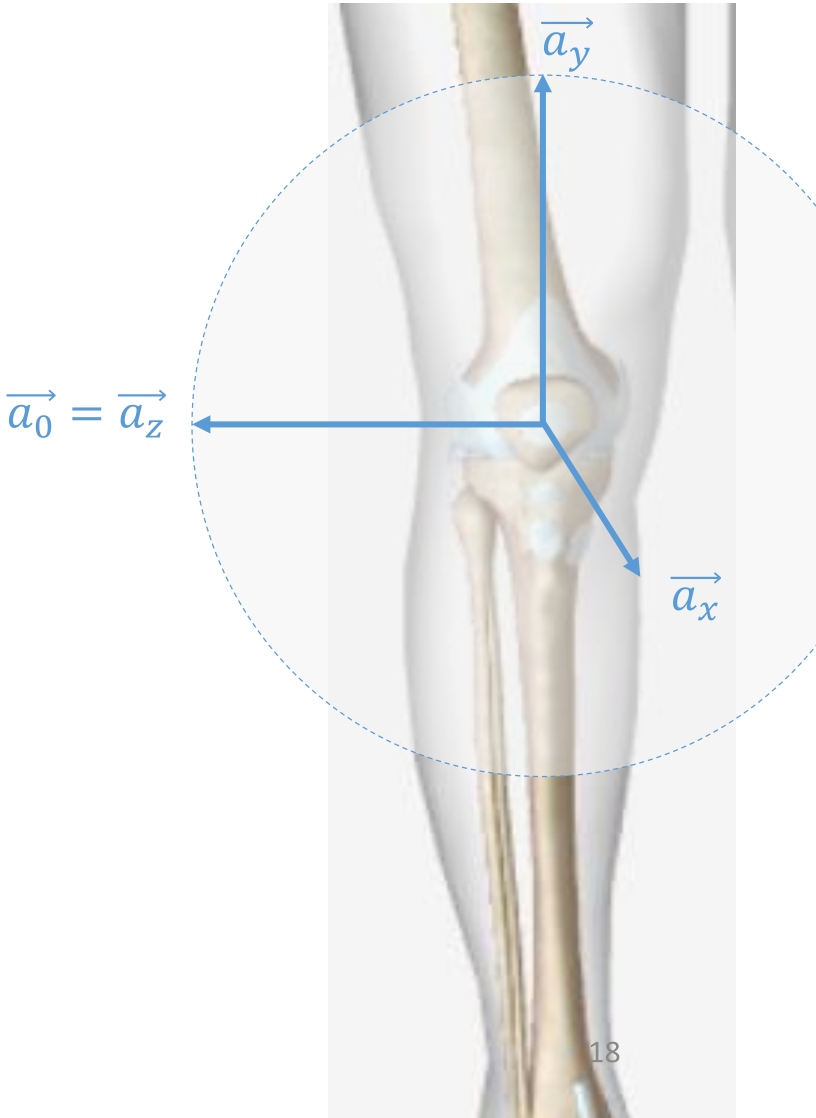




What is CusToM Doing ?

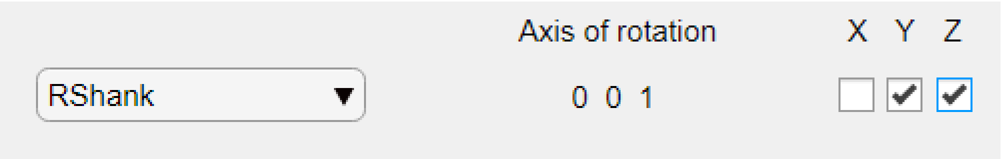
```
Geometrical Calibration ...
... Geometrical Calibration done
```

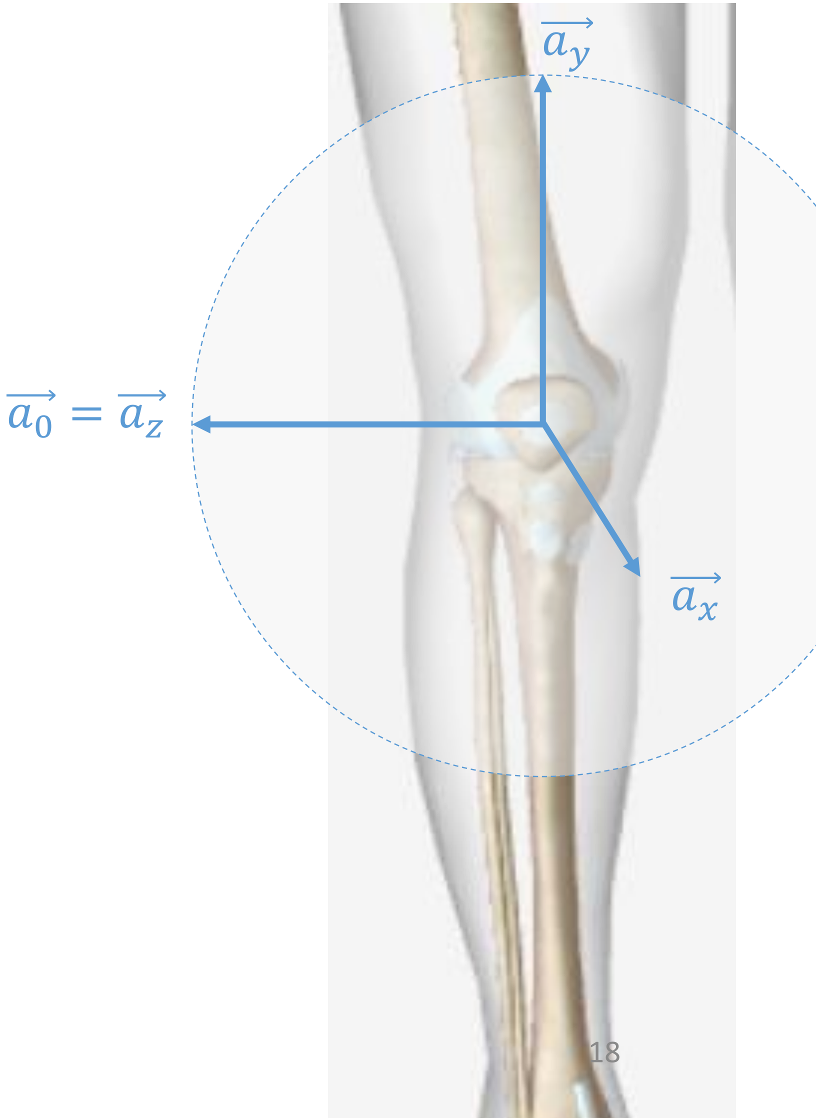
Axis of rotation

$$\overrightarrow{a_z}' = Rot(\alpha_1, \overrightarrow{a_x}) * \overrightarrow{a_0}$$

$$\overrightarrow{a_z}'' = Rot(\alpha_2, \overrightarrow{a_y}') * \overrightarrow{a_z}'$$

$$\overrightarrow{a_z}'' = Rot(\alpha_2, \overrightarrow{a_y}') * Rot(\alpha_1, \overrightarrow{a_x}) * \overrightarrow{a_0}$$





What is CusToM Doing ?

```
Geometrical Calibration ...
... Geometrical Calibration done
```

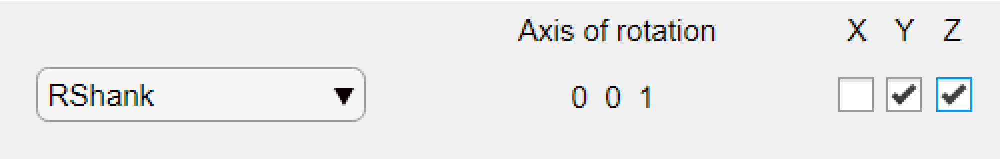
Axis of rotation

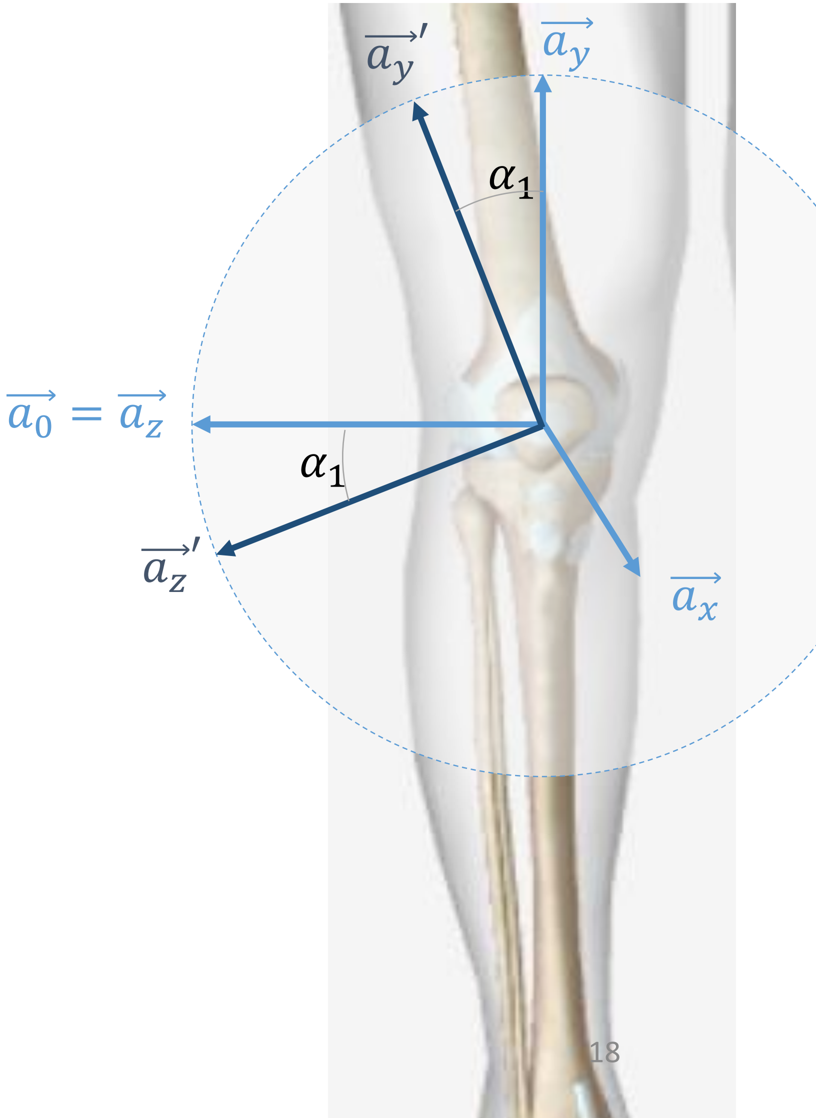
α_1

$$\overrightarrow{a_z}' = Rot(\alpha_1, \overrightarrow{a_x}) * \overrightarrow{a_0}$$

$$\overrightarrow{a_z}'' = Rot(\alpha_2, \overrightarrow{a_y}') * \overrightarrow{a_z}' \quad \alpha_1$$

$$\overrightarrow{a_z}'' = Rot(\alpha_2, \overrightarrow{a_y}') * Rot(\alpha_1, \overrightarrow{a_x}) * \overrightarrow{a_0}$$





What is CusToM Doing ?

```
Geometrical Calibration ...
... Geometrical Calibration done
```

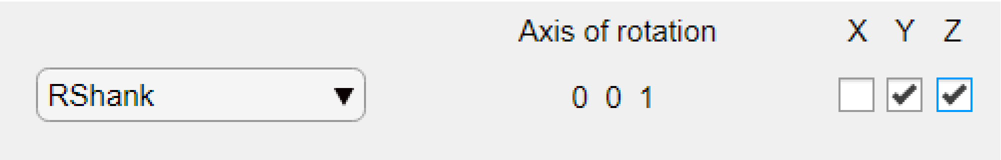
Axis of rotation

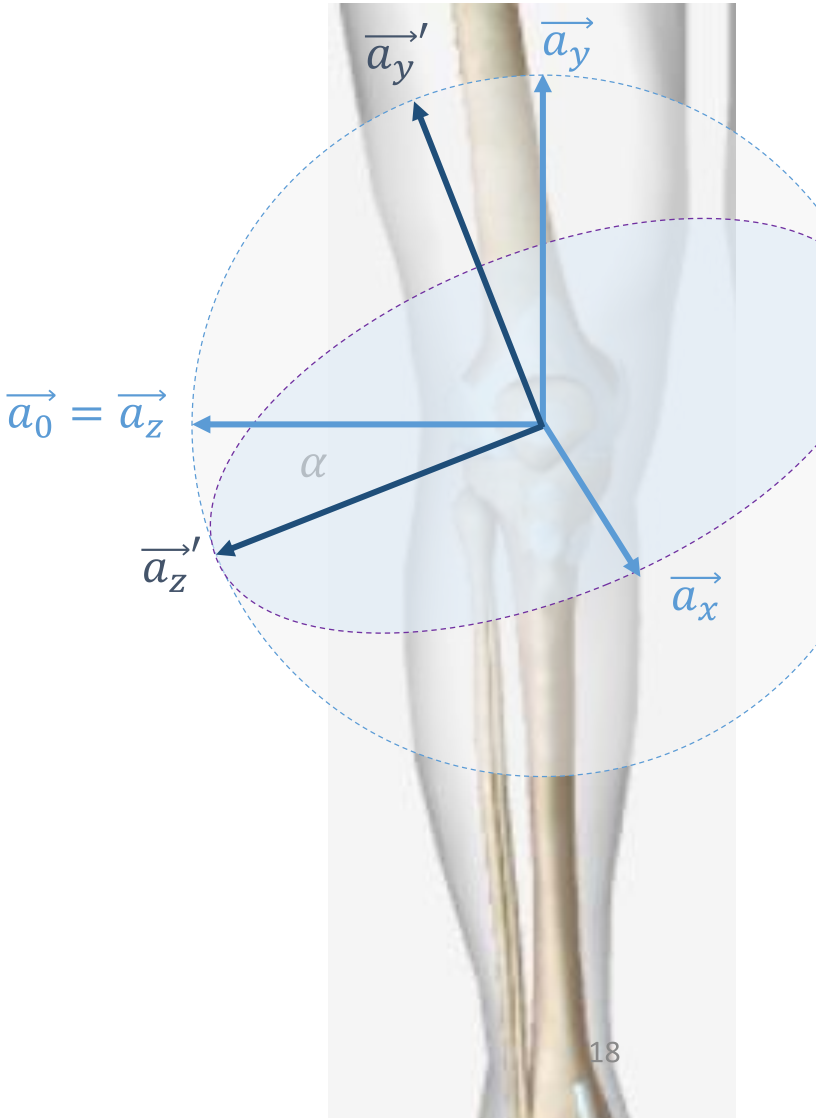
α_1

$$\overrightarrow{a_z}' = Rot(\alpha_1, \overrightarrow{a_x}) * \overrightarrow{a_0}$$

$$\overrightarrow{a_z}'' = Rot\left(\alpha_2, \overrightarrow{a_y}'\right) * \overrightarrow{a_z}'$$ α_1

$$\overrightarrow{a_z}'' = Rot\left(\alpha_2, \overrightarrow{a_y}'\right) * Rot(\alpha_1, \overrightarrow{a_x}) * \overrightarrow{a_0}$$





What is CusToM Doing ?

```
Geometrical Calibration ...
... Geometrical Calibration done
```

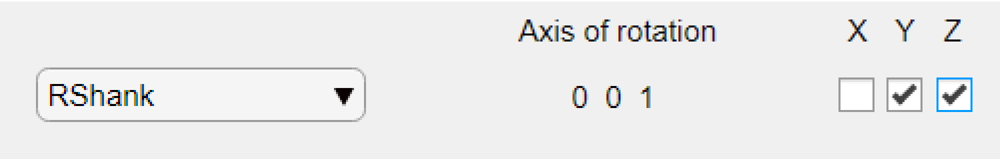
Axis of rotation

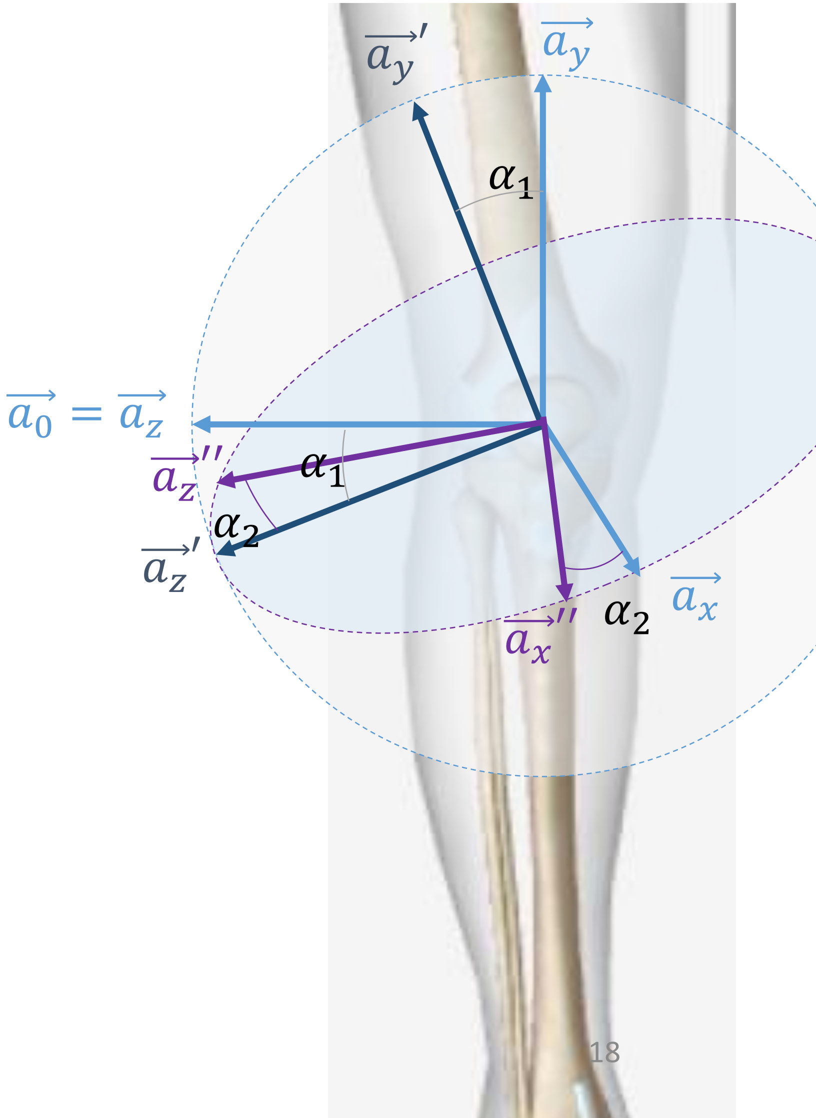
α_1

$$\overrightarrow{a_z}' = Rot(\alpha_1, \overrightarrow{a_x}) * \overrightarrow{a_0}$$

$$\overrightarrow{a_z}'' = Rot\left(\alpha_2, \overrightarrow{a_y}'\right) * \overrightarrow{a_z}' \quad \alpha_1$$

$$\overrightarrow{a_z}'' = Rot\left(\alpha_2, \overrightarrow{a_y}'\right) * Rot(\alpha_1, \overrightarrow{a_x}) * \overrightarrow{a_0}$$





What is CusToM Doing ?

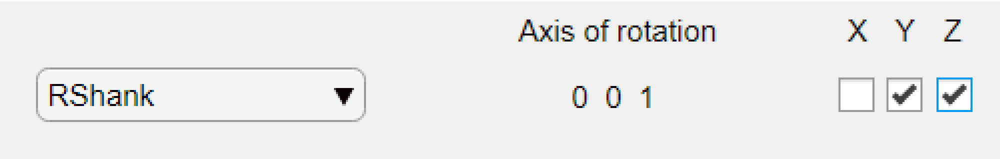
```
Geometrical Calibration ...
... Geometrical Calibration done
```

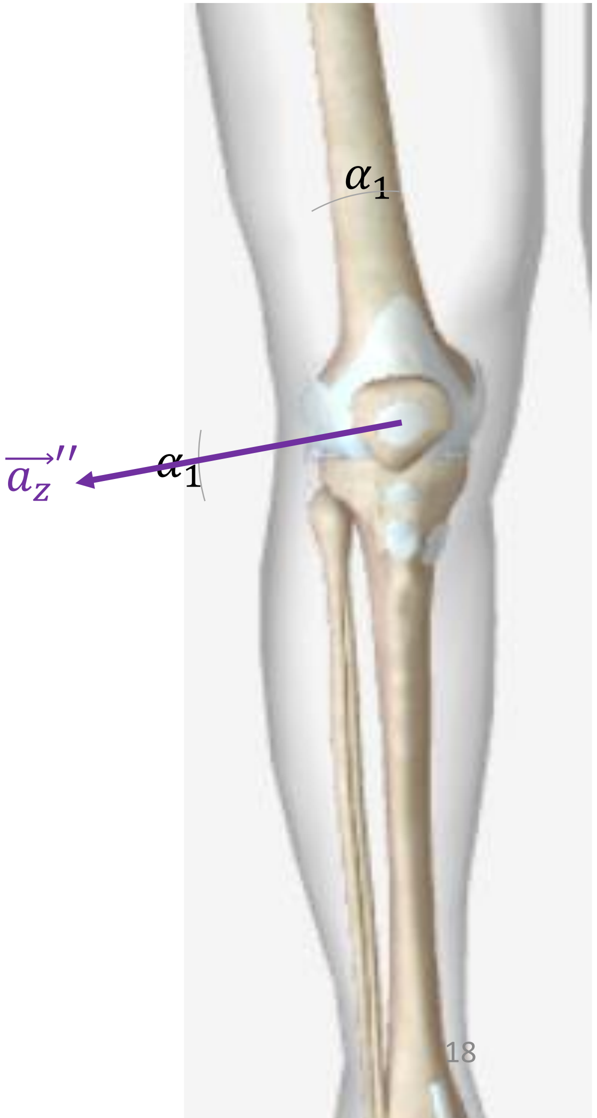
Axis of rotation

$$\overrightarrow{a_z}' = Rot(\alpha_1, \overrightarrow{a_x}) * \overrightarrow{a_0}$$

$$\overrightarrow{a_z}'' = Rot\left(\alpha_2, \overrightarrow{a_y}'\right) * \overrightarrow{a_z}'$$

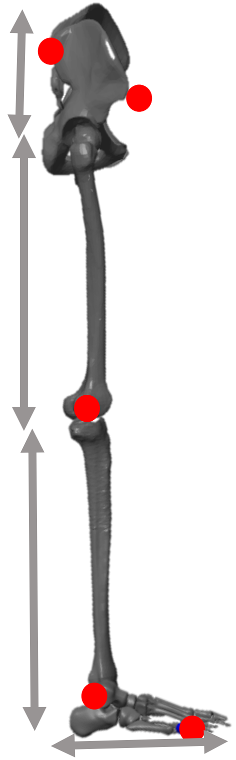
$$\overrightarrow{a_z}'' = Rot\left(\alpha_2, \overrightarrow{a_y}'\right) * Rot(\alpha_1, \overrightarrow{a_x}) * \overrightarrow{a_0}$$





What is CusToM Doing ? – Geometrical Calibration Process

```
Geometrical Calibration ...
... Geometrical Calibration done
```



Regression method
Based on height
RM

What is CusToM Doing ? – Geometrical Calibration Process

```
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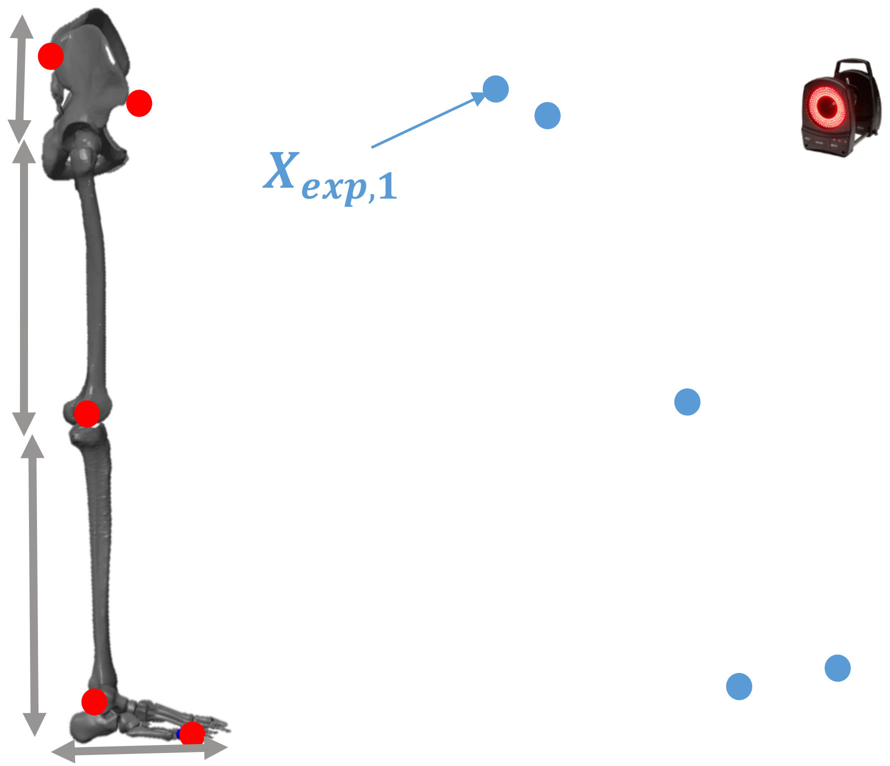
... Geometrical Calibration done
```

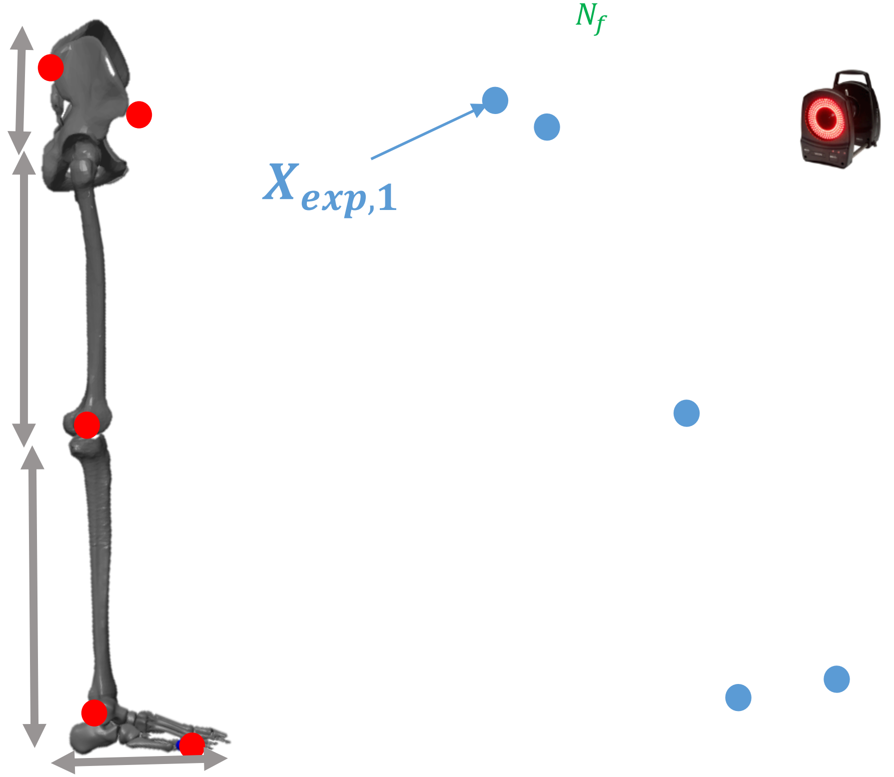


What is CusToM Doing ? – Geometrical Calibration Process

```
Geometrical Calibration ...
... Geometrical Calibration done
```

Equally spaced sets of frames:

N_f



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... Geometrical Calibration done
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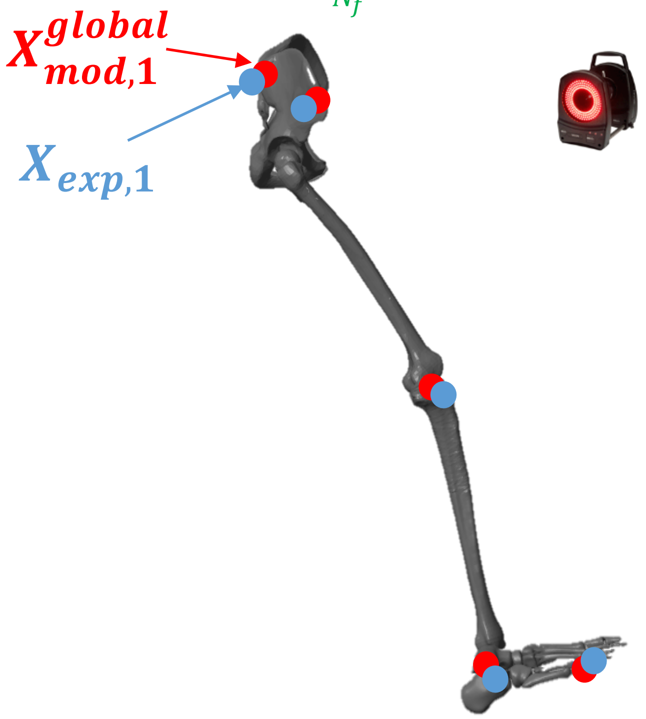
N_f



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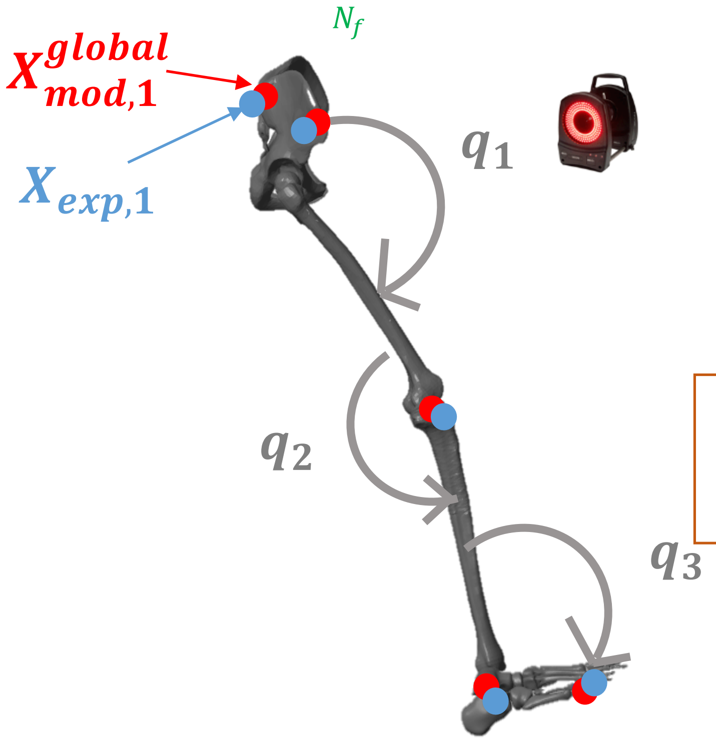
... Geometrical Calibration done
```

Equally spaced sets of frames:



Inverse kinematics

Lu and O'Connor et al. 1999

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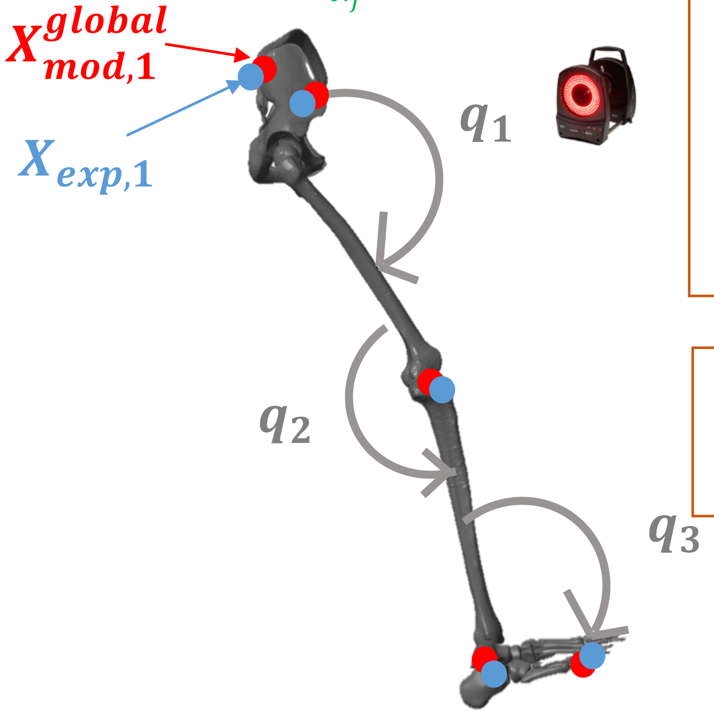
... Geometrical Calibration done
```

Equally spaced sets of frames:

N_f



Muller et al. 2015

Parameters identification

At each iteration i

$$\min_{k,\Delta p,\alpha} \phi_i = \sum_{f}^{N_f} \sum_{m}^{N_m} \left\| X_{exp,m}(t_f) - X_{mod,m}^{global}(t_f, k, \Delta p, \alpha) \right\|^2$$

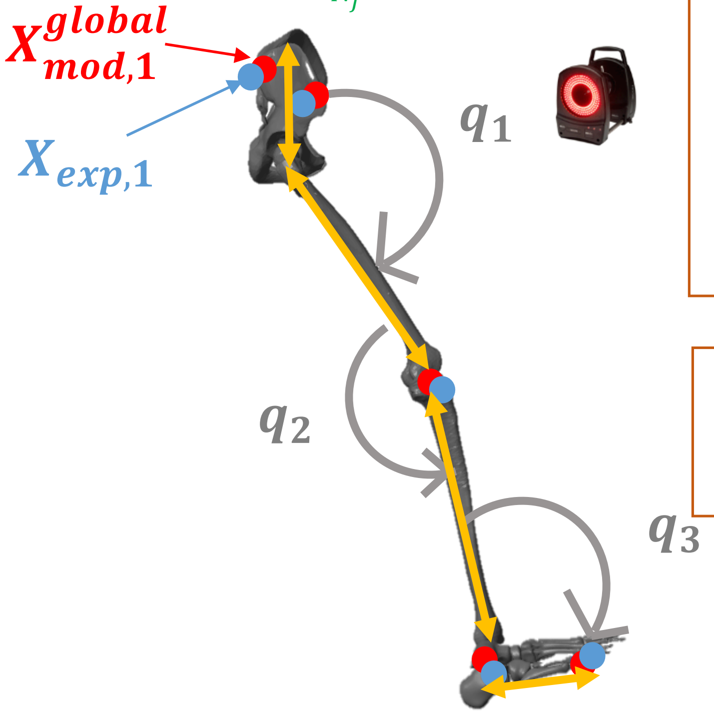
Inverse kinematics

Lu and O'Connor et al. 1999

What is CusToM Doing ? – Geometrical Calibration Process

```
Geometrical Calibration ...
... Geometrical Calibration done
```

Equally spaced sets of frames: N_f



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Inverse kinematics

Lu and O'Connor et al. 1999

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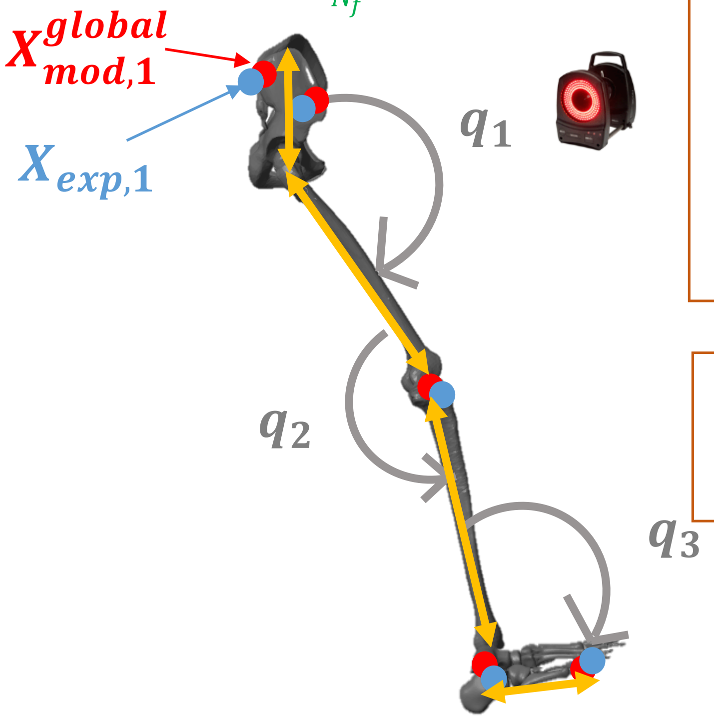
Geometrical Calibration ...
... Geometrical Calibration done
```

Equally spaced sets of frames: N_f



Muller et al. 2015

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Inverse kinematics

Lu and O'Connor et al. 1999

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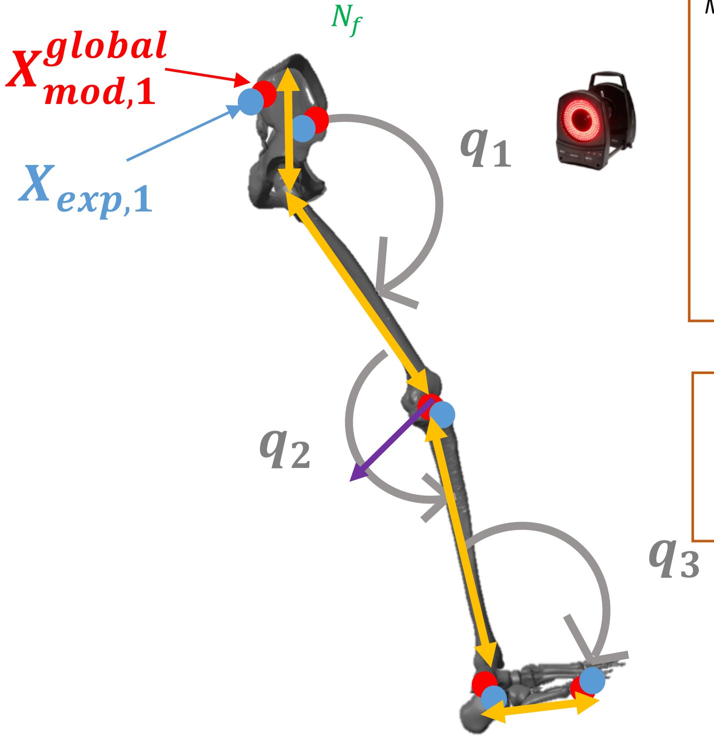

Muller et al. 2015

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At each iteration i

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Lu and O'Connor et al. 1999

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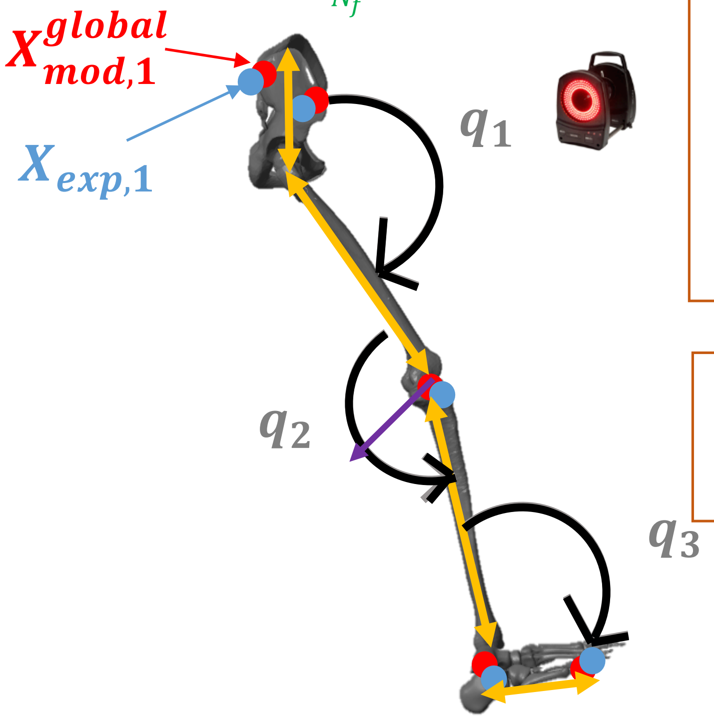
N_f



Muller et al. 2015

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Lu and O'Connor et al. 1999

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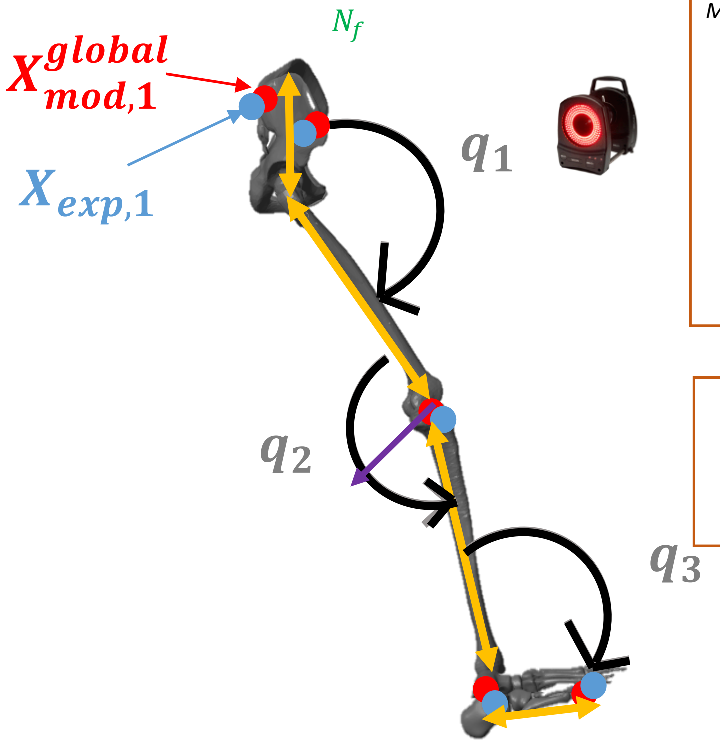

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Inverse kinematics

Lu and O'Connor et al. 1999

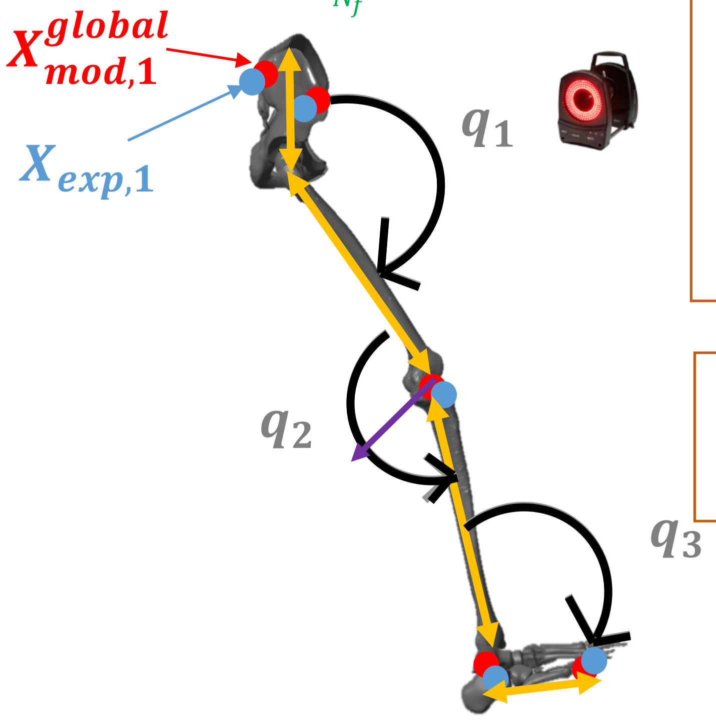
Criterion satisfied ?

$$\frac{\phi_i - \phi_{i-1}}{\phi_{i-1}} < 5\%$$

What is CusToM Doing ? – Geometrical Calibration Process

```
Geometrical Calibration ...
... Geometrical Calibration done
```

Equally spaced sets of frames: N_f



Muller et al. 2015

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Inverse kinematics

Lu and O'Connor et al. 1999

Criterion satisfied ?

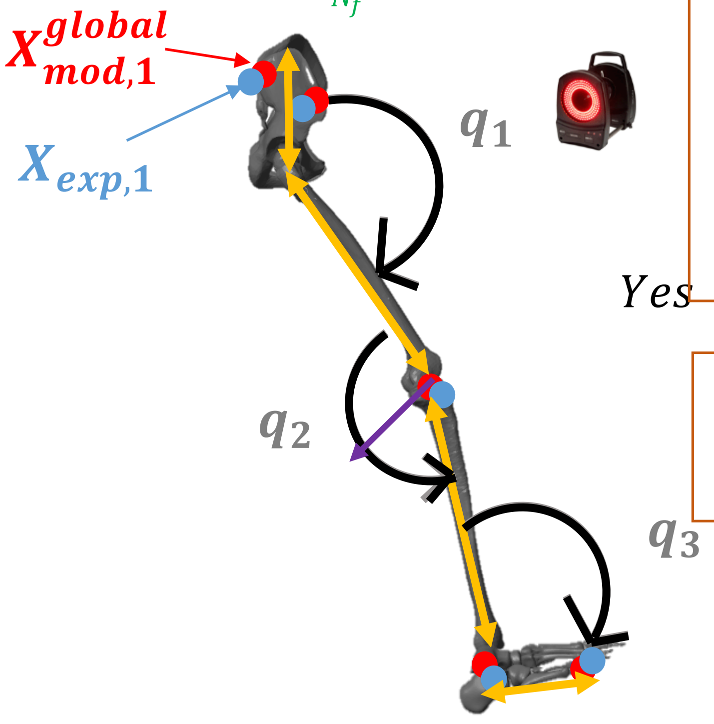
$$\frac{\phi_i - \phi_{i-1}}{\phi_{i-1}} < 5\%$$

No

What is CusToM Doing ? – Geometrical Calibration Process

```
Geometrical Calibration ...
... Geometrical Calibration done
```

Equally spaced sets of frames: N_f



Muller et al. 2015

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At each iteration i

$$\min_{k,\Delta p,\alpha} \phi_i = \sum_f^{N_f} \sum_m^{N_m} \left\| X_{exp,m}(t_f) - X^{global}_{mod,m}(t_f, k, \Delta p, \alpha) \right\|^2$$

Yes

Inverse kinematics

Lu and O'Connor et al. 1999

Criterion satisfied ?

$$\frac{\phi_i - \phi_{i-1}}{\phi_{i-1}} < 5\%$$

No

Yes

Stop

What is CusToM Doing ?

```
Geometrical Calibration ...
... Geometrical Calibration done
```

$$\Phi = \sum_{f}^{N_f} \sum_{m}^{N_m} ||\mathbf{X}_{exp,m}(t_f) - \mathbf{X}_{mod,m}^{R_{global}}(\mathbf{q}(t_f), \mathbf{k}, \boldsymbol{\alpha}, \mathbf{\Delta p})||^2$$

$$\begin{aligned} \min_{\mathbf{k},\boldsymbol{\alpha},\mathbf{\Delta p}} \quad & \Phi(\mathbf{q}(t_f), \mathbf{k}, \boldsymbol{\alpha}, \mathbf{\Delta p}) \\ \text{s.t.} \quad & \forall\ s\ \in [\![1; N_s]\!],\ |\frac{k_s}{k_s^0} - 1| < 20\ \% \\ & \forall\ a\ \in [\![1; N_\alpha]\!],\ \alpha_{a,min} < \alpha_a < \alpha_{a,max} \\ & \forall\ m \in [\![1; N_m]\!],\ |\Delta p_m| < 0.05\ m \end{aligned}$$

$$\epsilon = \frac{\Phi_i - \Phi_{i-1}}{\Phi_{i-1}}$$

Geometrical Calibration Results

```
>> PostProcessingCalibration
```

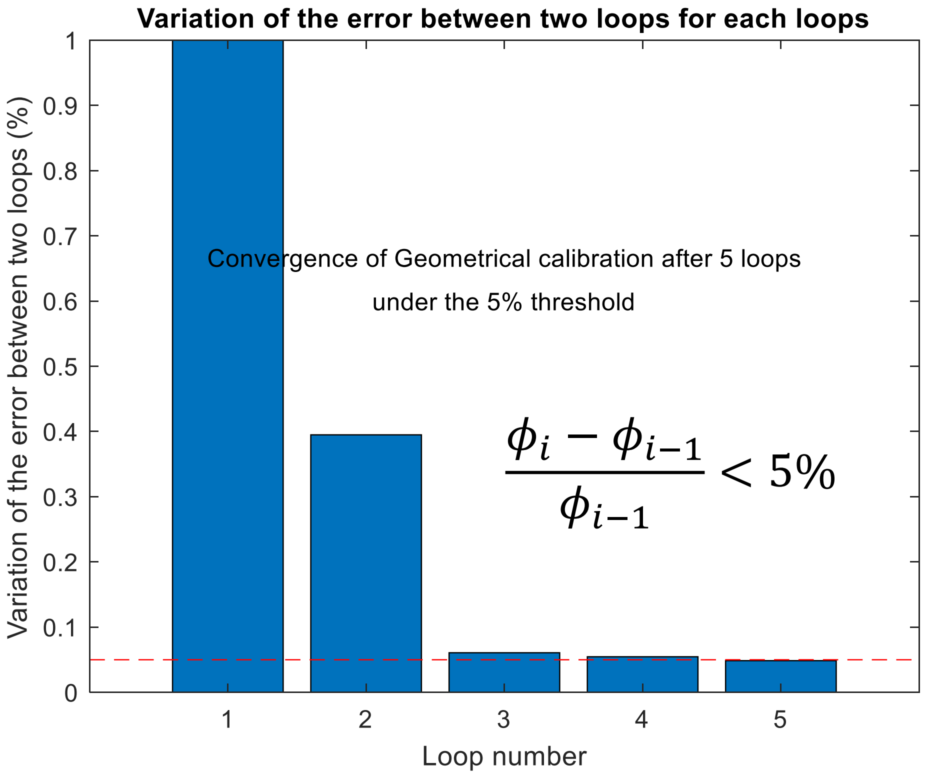
All contained in a struct :

BiomechanicalModel.GeometricalCalibration

Field	Value
frame_calib	1x20 double
crit	[1 0.4682 0.0703 0.0989 0.0414]
errorm	1x5 cell
k_calib	48x1 double
p_calib	126x1 double
alpha_calib	[ ]

`BiomechanicalModel.GeometricalCalibration`

« `.Crit` »



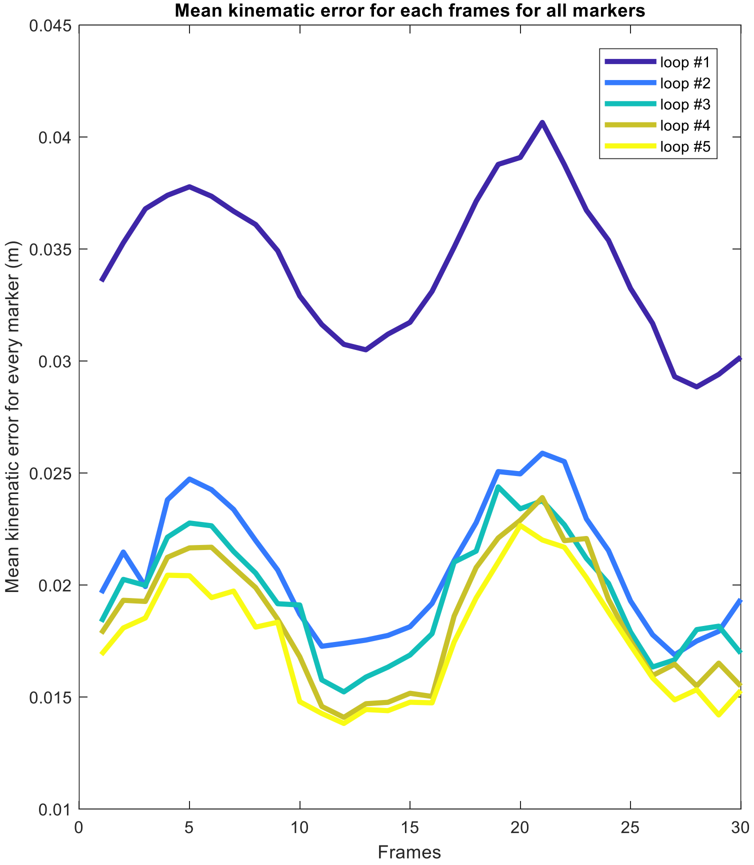
$$\frac{\phi_i - \phi_{i-1}}{\phi_{i-1}} < 5\%$$

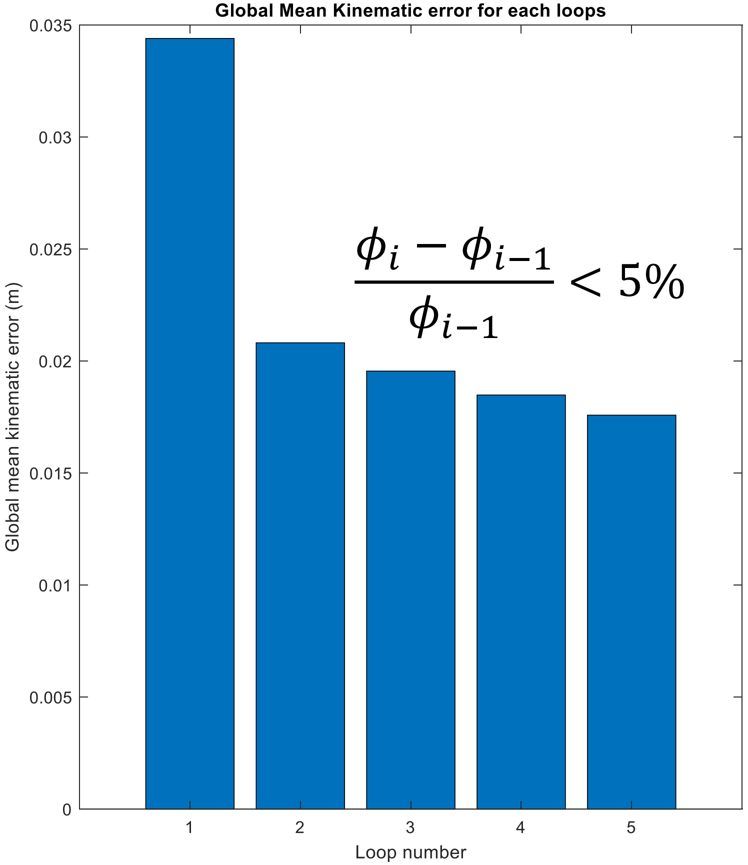
Geometrical Calibration Results

```
>> PostProcessingCalibration
```

`BiomechanicalModel.GeometricalCalibration`

« `.errorm` »





$$\frac{\phi_i - \phi_{i-1}}{\phi_{i-1}} < 5\%$$

Geometrical Calibration Results

```
>> PostProcessingCalibration
```

`BiomechanicalModel.GeometricalCalibration`

« `.calib_k` »

k_calib   48x1 double

BiomechanicalModel.GeometricalCalibration.k_calib

	1	2	3	4
1	0.9646			
2	1			
3	1			
4	1			
5	1			
6	1			
7	0.9487			
8	1			
9	1			
10	0.9487			
11	1			
12	1			
13	0.9487			
14	1			
15	1			
16	0.9336			

Variation of the homothetic coefficient from the anthopometric estimation.

Reminder:

$$k_0 = \frac{size\ of\ the\ subject}{size\ of\ the\ cadaver}$$

From the initial musculoskeletal model:

BiomechanicalModel.OsteoArticularModel

Fields	name	sister	child
1	'PelvisSacr...	0	2
2	'LowerTrun...	17	3
3	'LowerTrun...	0	4
4	'LowerTrunk'	0	5
5	'UpperTrun...	0	6
6	'UpperTrun...	0	7
7	'Thorax'	0	8
8	'RClavicle_J...	11	9
9	'RClavicle_J...	0	10
10	'RClavicle'	0	29
11	'LClavicle_J1'	14	12
12	'LClavicle_J2'	0	13
13	'LClavicle'	0	36
14	'ThoraxSkul...	0	15
15	'ThoraxSkul...	0	16

$$k_{final} = k_0 * k_{calib}$$

Geometrical Calibration Results

```
>> PostProcessingCalibration
```

BiomechanicalModel.GeometricalCalibration

« .calib_p »

Displacement of the marker in local frames.

p_calib 126x1 double

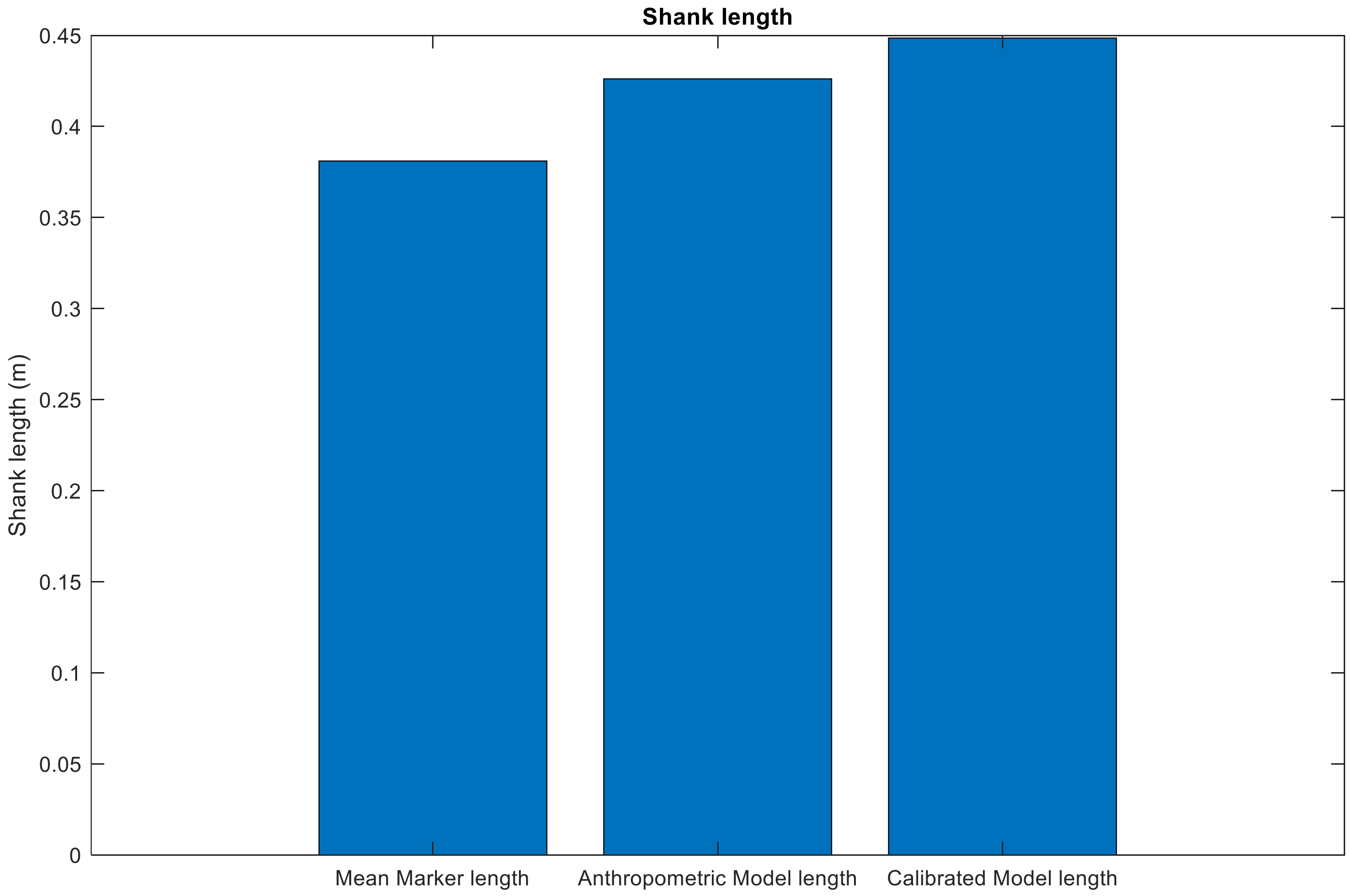
BiomechanicalModel.GeometricalCalibration.p_calib

	1	2	3	4
1	0	$\vec{x}$		
2	-0.0037	$\vec{y}$		
3	0	$\vec{z}$		
4	0.0210			
5	0			
6	0			
7	0			
8	-0.0271			
9	0			
10	-0.0181			
11	-0.0111			
12	0			
13	2.8682e-04			
14	0			
15	0.0218			
16	0.0067			

BiomechanicalModel.Markers

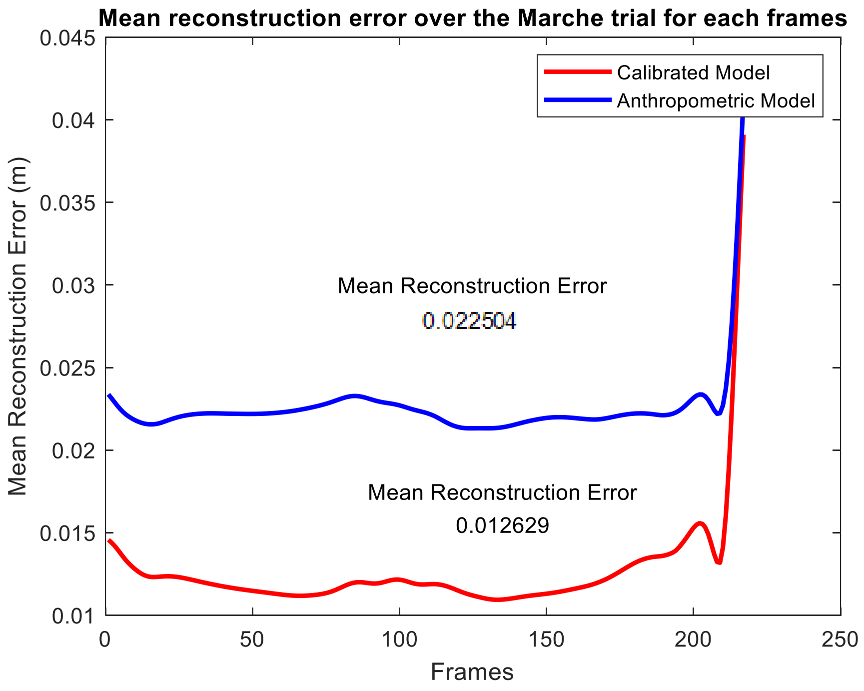
Fields	name	anat_position	calib_
1	'STRN'	'STRN'	3x1 cell
2	'CLAV'	'CLAV'	3x1 cell
3	'T10'	'T10'	3x1 cell
4	'C7'	'C7'	3x1 cell
5	'RSHO'	'RSHO'	3x1 cell
6	'LSHO'	'LSHO'	3x1 cell
7	'RFWT'	'RFWT'	3x1 cell
8	'LFWT'	'LFWT'	3x1 cell
9	'RBWT'	'RBWT'	3x1 cell
10	'LBWT'	'LBWT'	3x1 cell
11	'RFHD'	'RFHD'	3x1 cell
12	'LFHD'	'LFHD'	3x1 cell
13	'RBHD'	'RBHD'	3x1 cell
14	'LBHD'	'LBHD'	3x1 cell
15	'RKNE'	'RKNE'	3x1 cell
16	'RANE'	'RANE'	3x1 cell

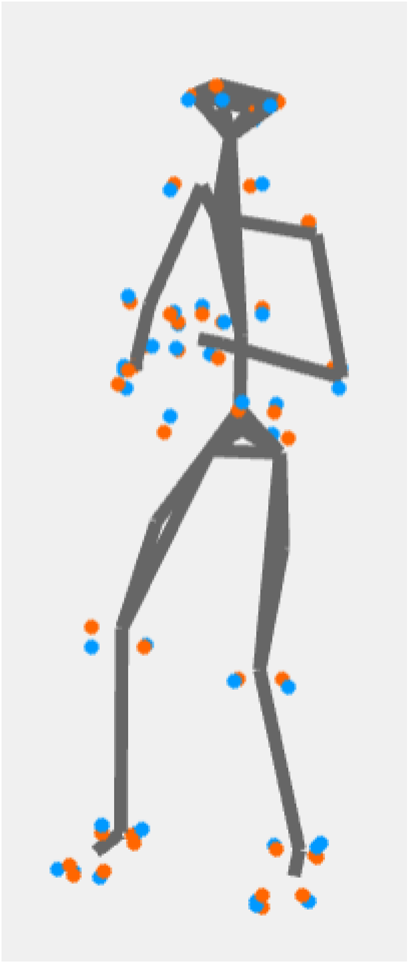
What about the quality of the model ?
Geometrical Calibration Results - Right Shank length



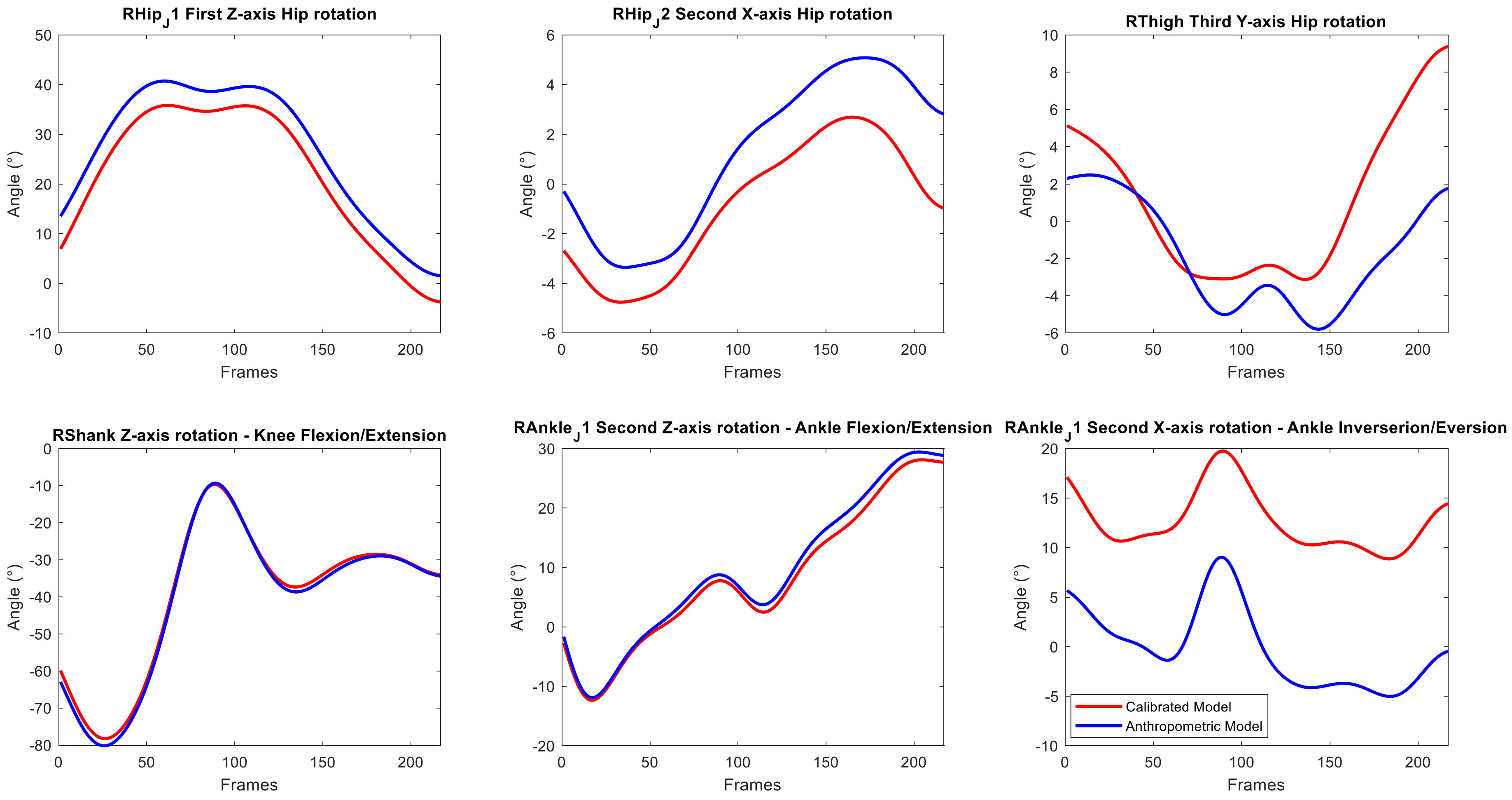
Kinematical Results

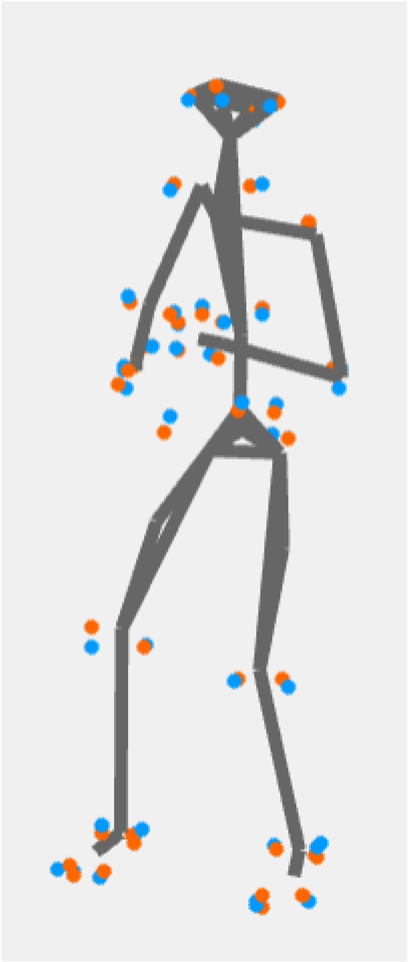
Decreasing of the mean reconstruction error over the side step trial.



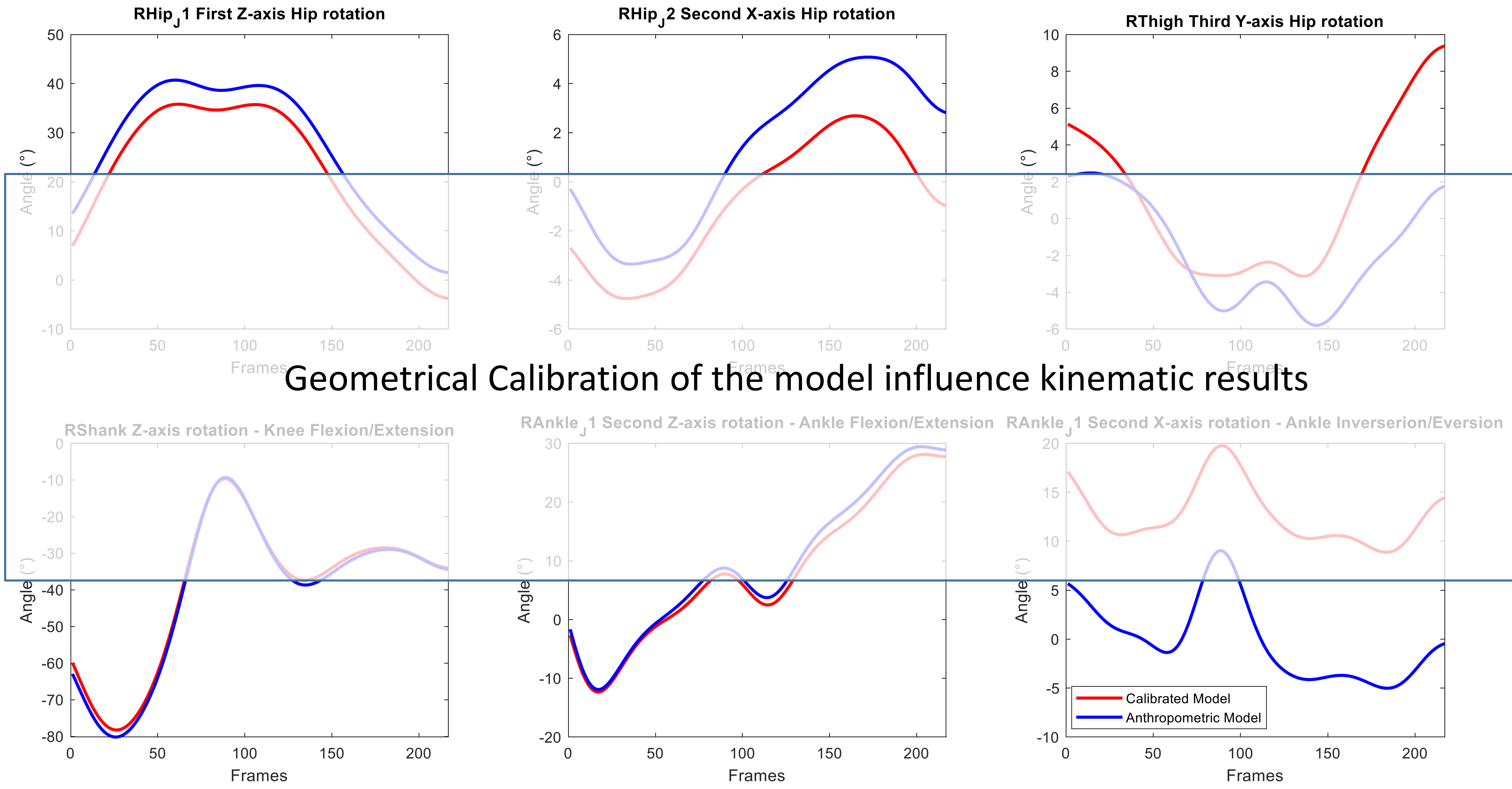


Kinematical Results

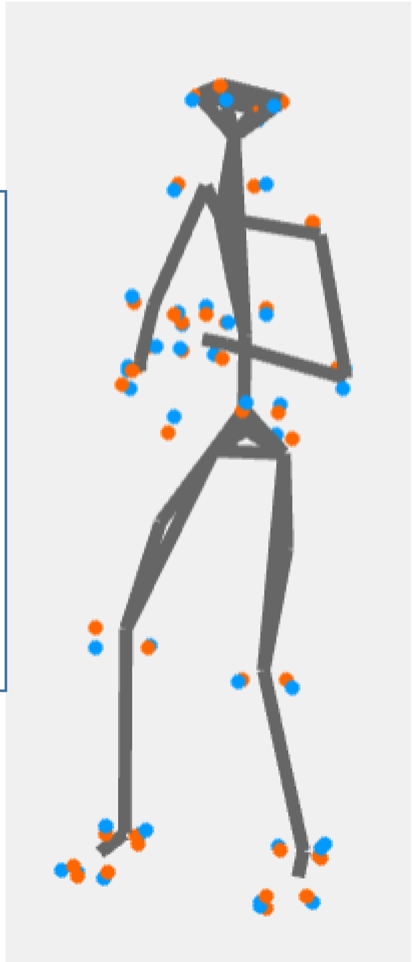




Kinematical Results



Geometrical Calibration of the model influence kinematic results



Take home message

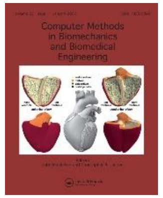
To ensure the quality of the model and kinematic results

- Check your reconstruction errors
  - on your calibration trial
  - on your inverse kinematic trials
  - 4 to 40 mm reconstruction error mean have been reported. [Begon et al. 2017]

Begon, M., Andersen, M.S., Dumas, R., 2017. Multibody kinematic optimization for the estimation of upper and lower limb human joint kinematics: a systematic review. J. Biomech. Eng. 140, 1–11.

- Be sure you chose the right constraints to ensure the geometrical calibration
  - Enough frames (20-100)
  - Homothetic constraints (equality)
  - Displacement of markers
  - Rotation of joint axis

Perspectives for scaling in CusToM



Accuracy and kinematics consistency of marker-based scaling approaches on a lower limb model: a comparative study with imagery data

P.Puchaud[a,b,c], C. Sauret[d], A. Muller[a,e], N. Bideau[b], G. Dumont[a], H. Pillet[d], C. Pontonnier[a,c]

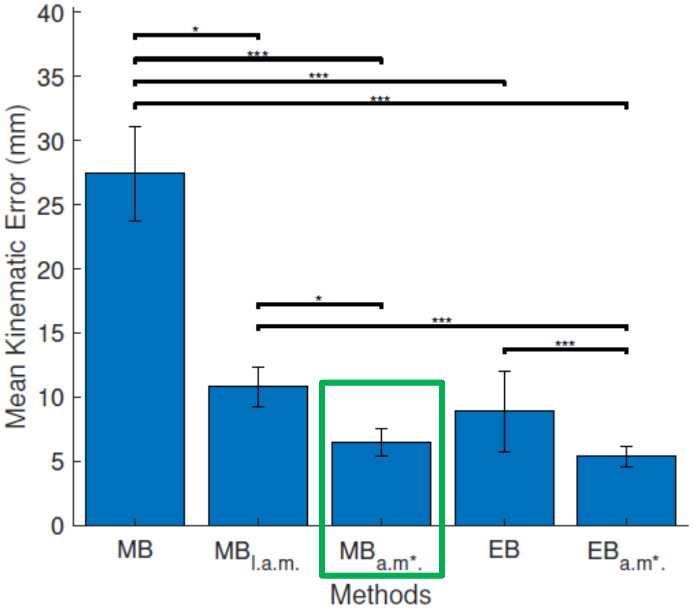


Figure 5. Kinematic errors (mean and standard deviation) on hip- and knee-joint functional movements withblue five models: HB, MB, $MB_{l.a.m.}$, $MB_{a.m^*.}$, EB and $EB_{a.m^*.}$. *,**,*** indicated respective p-values < 0.05, < 0.005, < 0.001 with respect to Tukey's honest significant difference criterion.

Skins Markers

Biplanar Radiographies

STEPS

1. Scaled bones based on markers locations
2. Optimize marker locations and joint axis orientations

BENEFITS

1. Consistent segment lengths (inter-hip sitance, femur, shank) compared with radiographies
2. Low kinematic residuals consistent with EOS models
3. Joint angles consistent with EOS models

Pre-Work

Go in `Examples\1_Walking\POC0980A_altered`

It contains :

Marche.c3d	16/12/2019 11:29	Fichier C3D
NormalizeAbscisseCurve100.m	30/01/2019 16:48	MATLAB Code
PostProcessingKinematic_Walking.m	16/12/2019 17:39	MATLAB Code
ROM01.c3d	28/01/2019 14:14	Fichier C3D

Context – New Example

Ankle Sprain over the world

1 /10,000 people /day *Katcherian D. 1994*

Context – New Example

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Treating the ankle sprain grade III:

- Immobilization

Mohammadi et al. 2013

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A kinematic analysis
with CusToM

Normal gait vs Altered gait

with an ankle brace

Botimed

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Mohammadi et al. 2013

A kinematic analysis with CusToM

Normal gait vs Altered gait

with an ankle brace

Research Question:

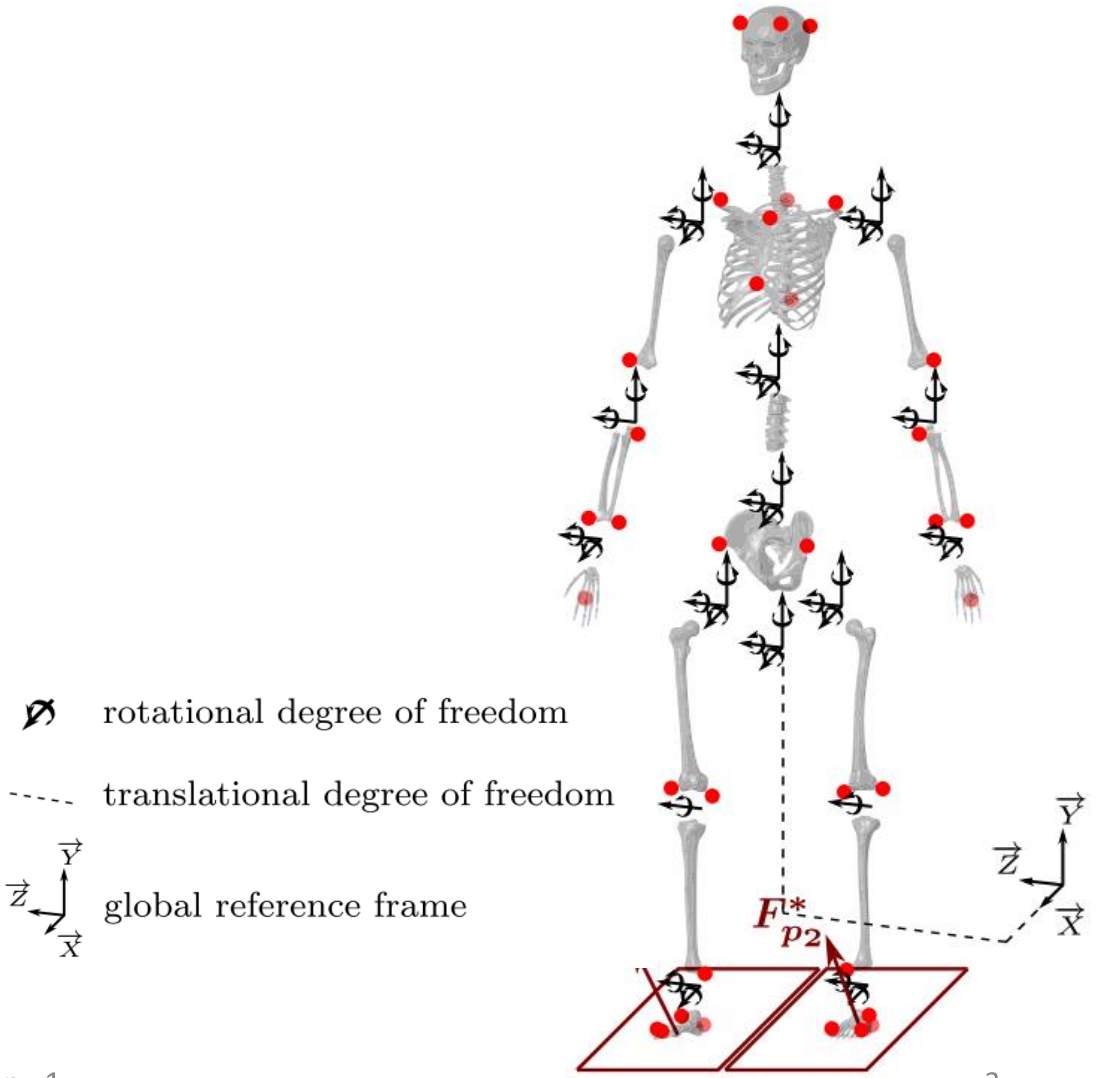
What are the kinematical compensation strategies ?

Generate Parameters of the Model

```
>> GenerateParameters
```

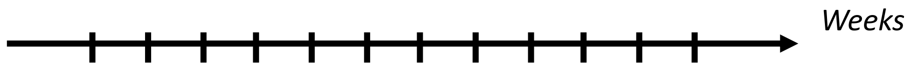
- Size : 1.74 m
- **Mass : 62,5 Kg**

- Osteo-articular model – full body
  - **Leg – Leg without Ankle**
- Marker Set
  - MarkerSet_2 (M2S makerset)
  - 1 markers on hand
- Leg Muscles



Data Collection

1 subject



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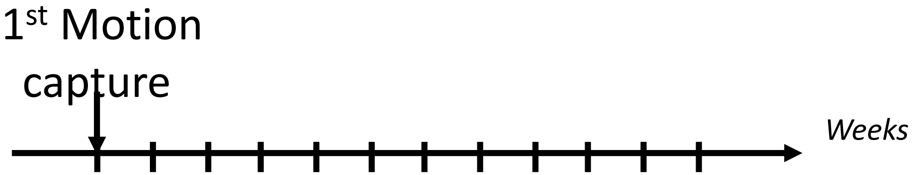

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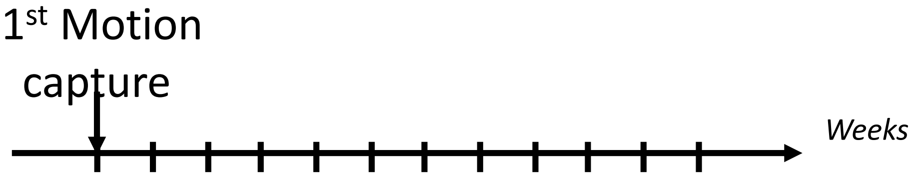
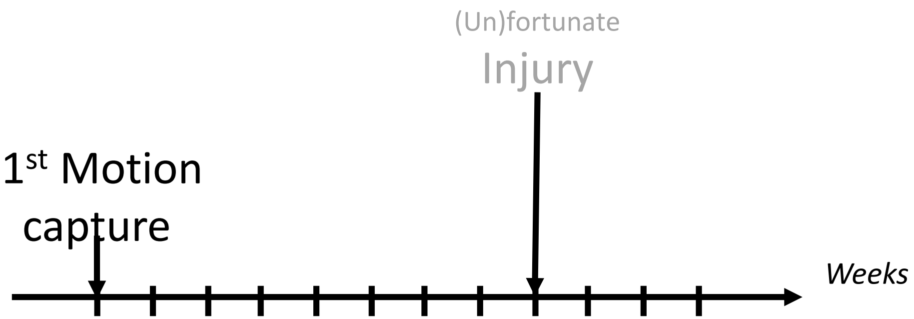


A modified plug-in-gait markerset

45 reflective markers

Data Collection

1 subject



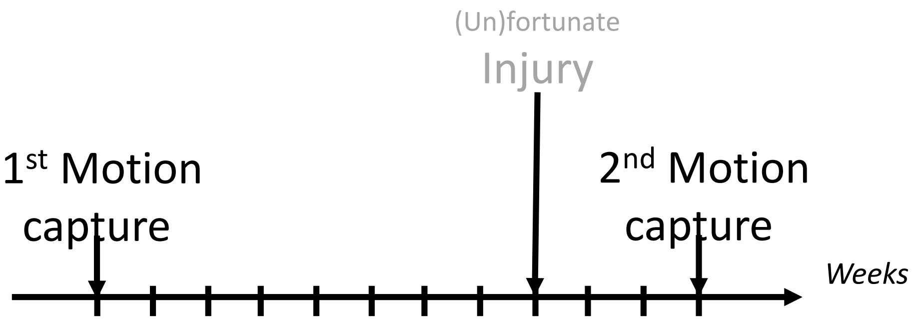
Complete tear of right lateral ankle ligament

A modified plug-in-gait markerset

45 reflective markers

Data Collection

1 subject



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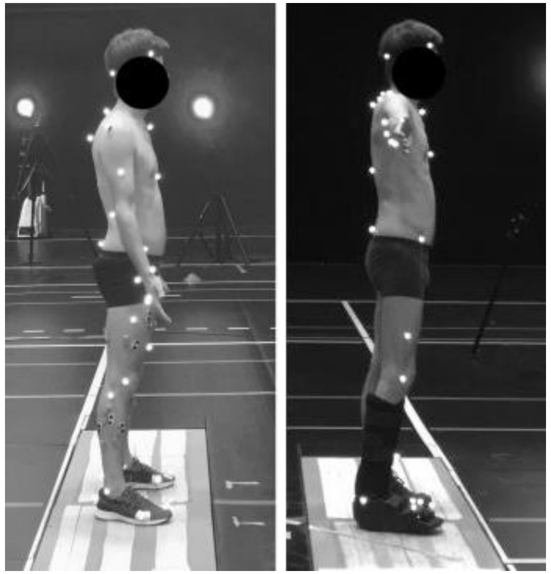
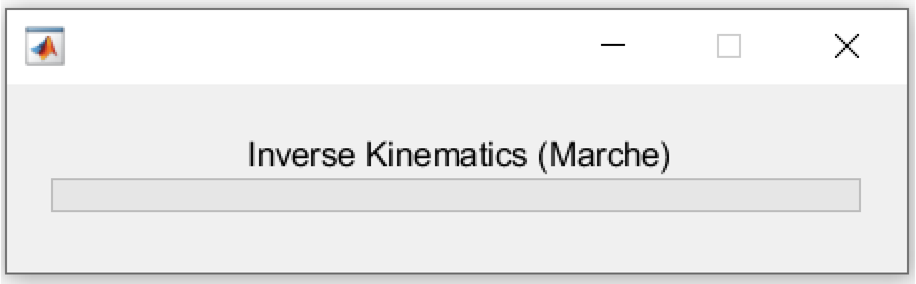


A modified plug-in-gait markerset

45 reflective markers

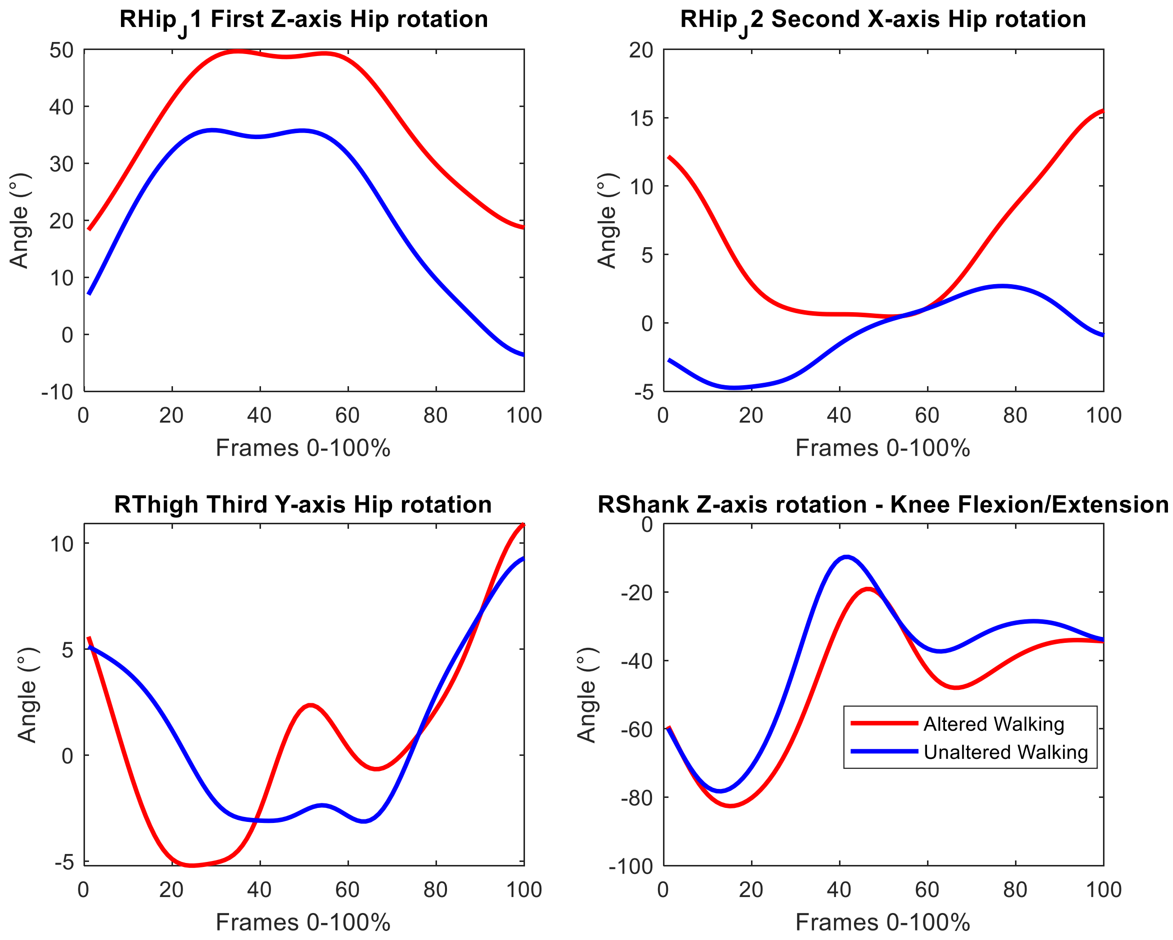
Run




```
Inverse kinematics (Marche) ...
... Inverse kinematics (Marche) done
```

Altered and normal gait comparison

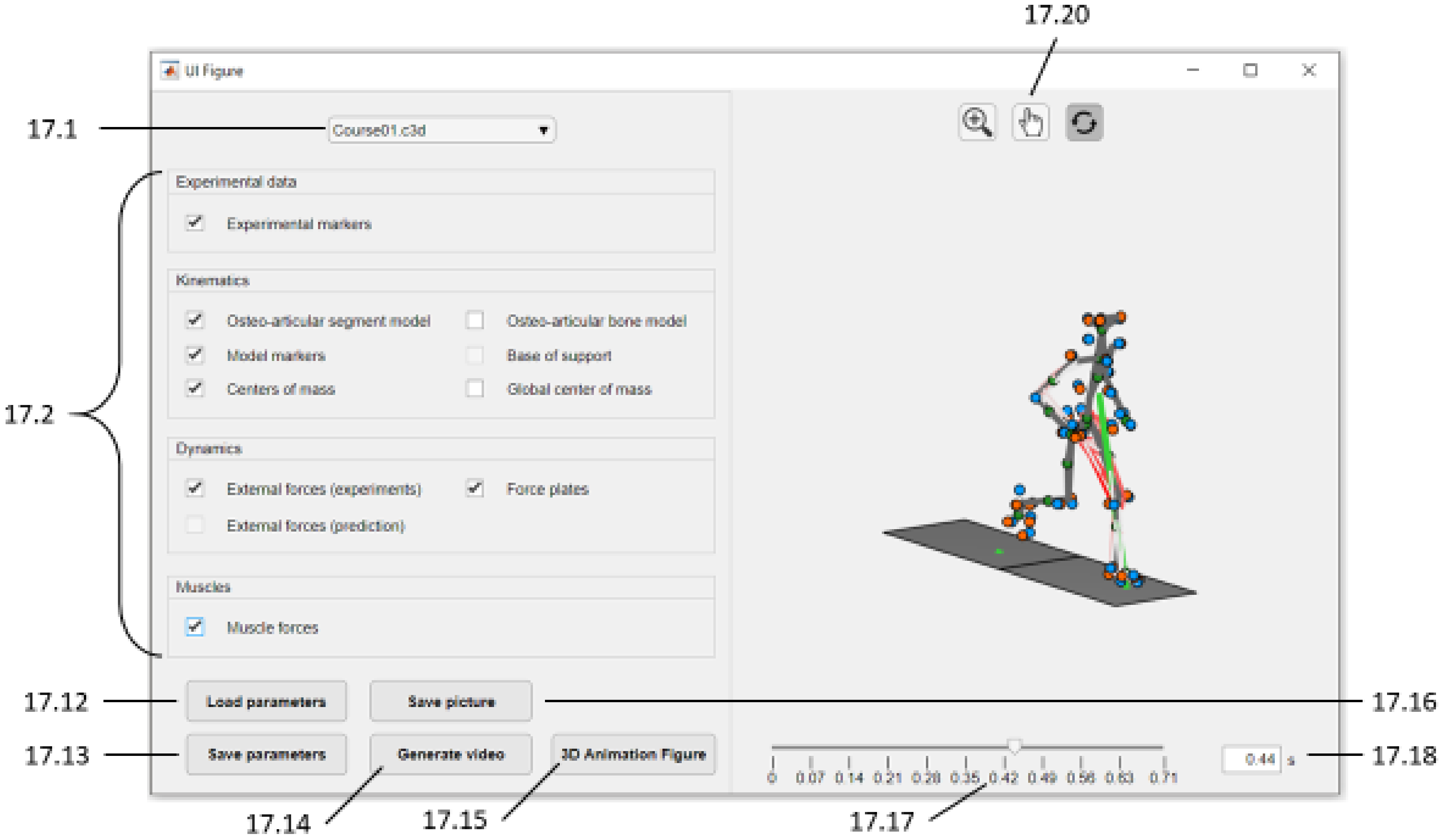
```
>> PostProcessingKinematic_Walking
```



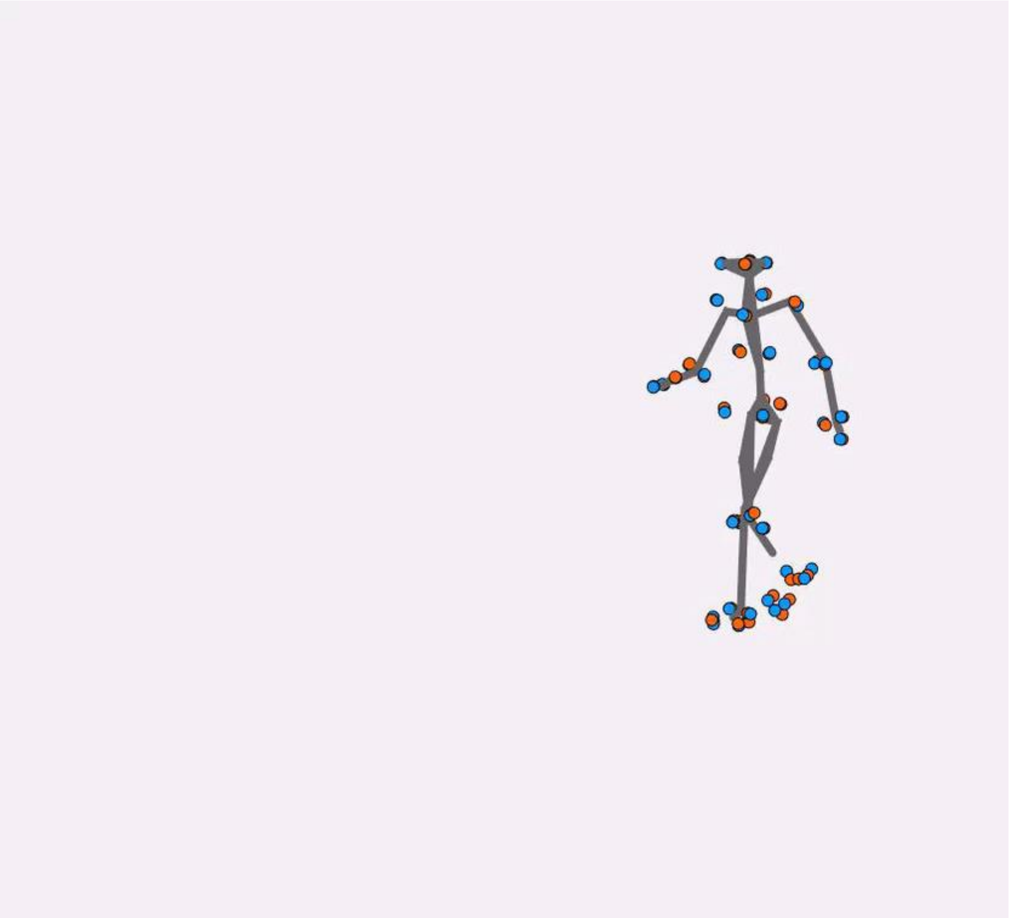
Hip circumduction

Visualization Tutorial

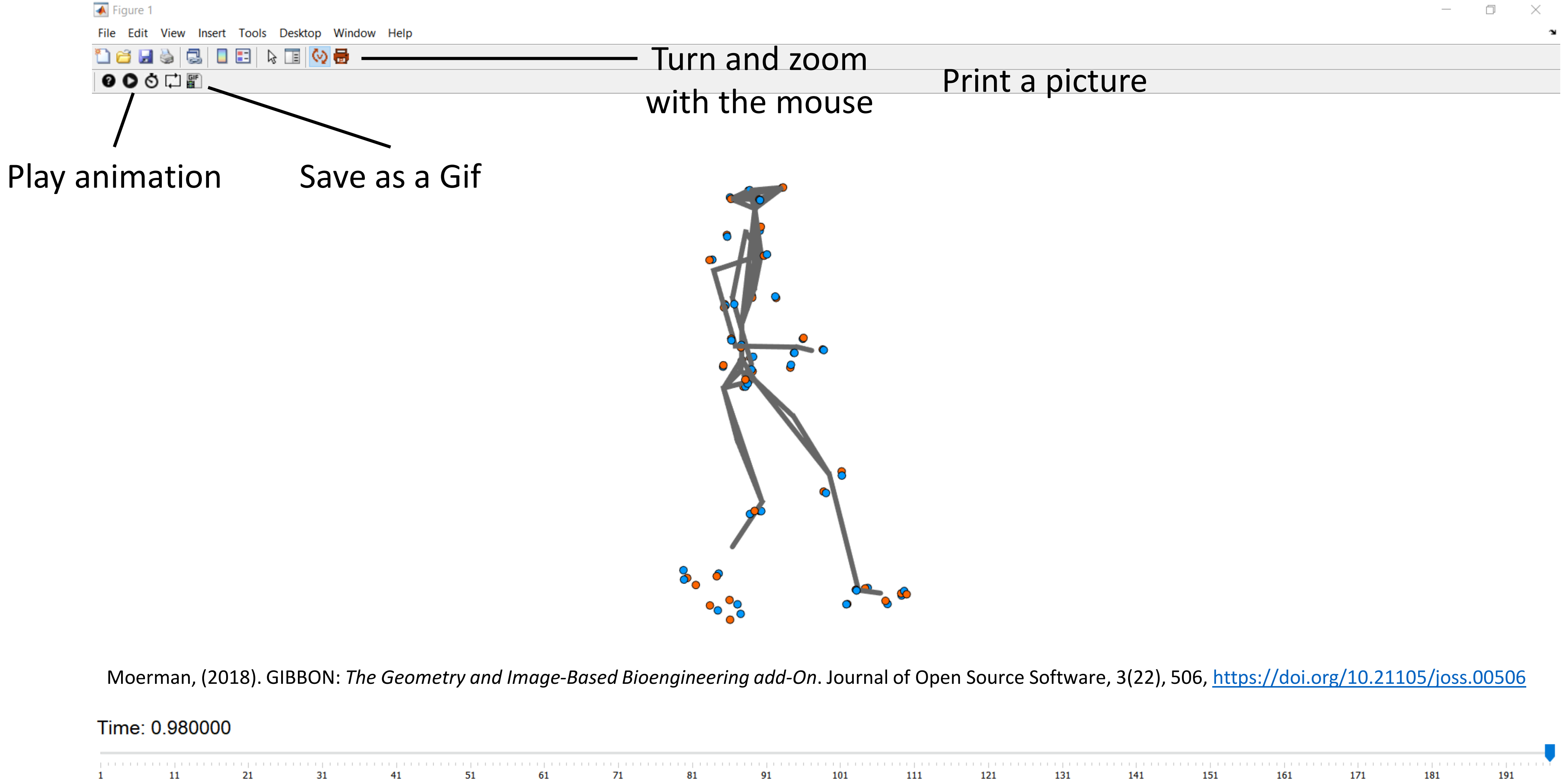
```
>>  GenerateAnimate
```



Video

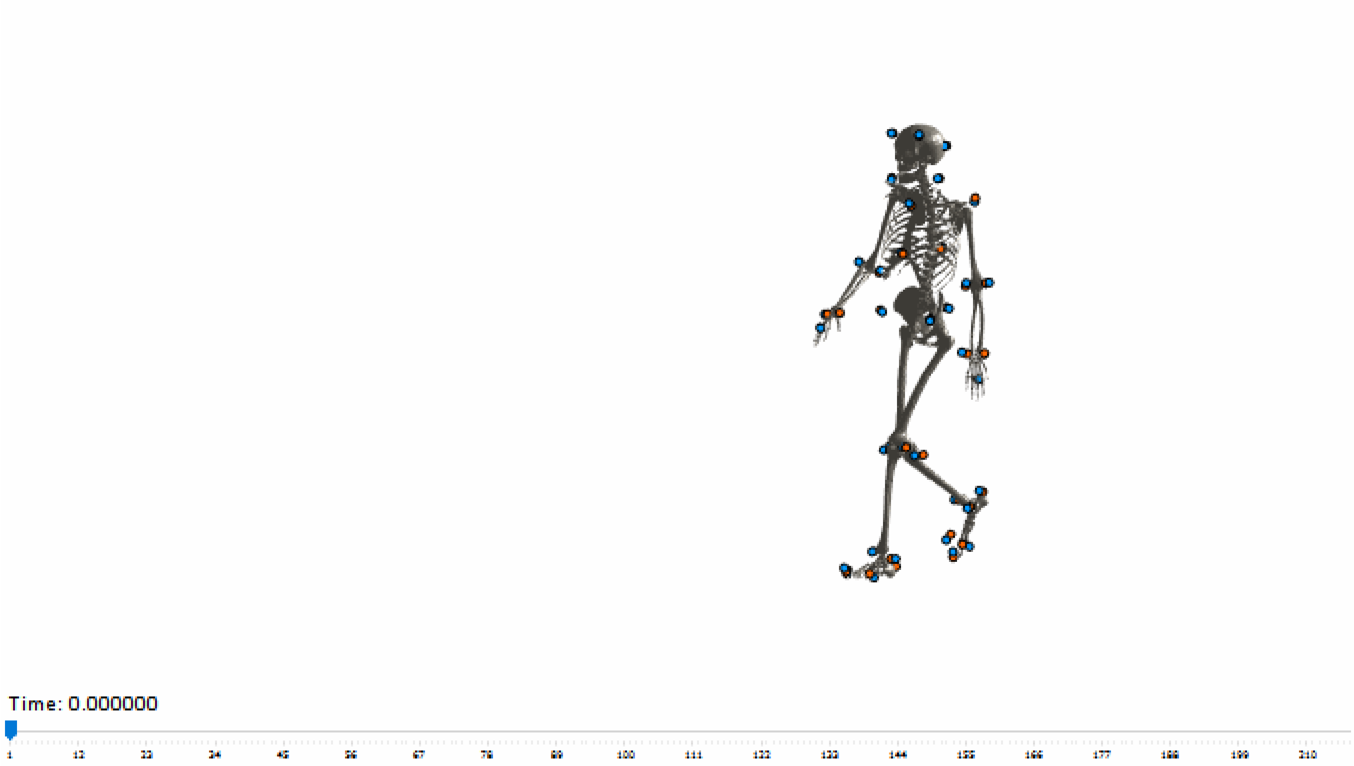


3D Animation Figure



Moerman, (2018). GIBBON: *The Geometry and Image-Based Bioengineering add-On*. Journal of Open Source Software, 3(22), 506, https://doi.org/10.21105/joss.00506

.Gif Export



Moerman, (2018). GIBBON: *The Geometry and Image-Based Bioengineering add-On*. Journal of Open Source Software, 3(22), 506, https://doi.org/10.21105/joss.00506