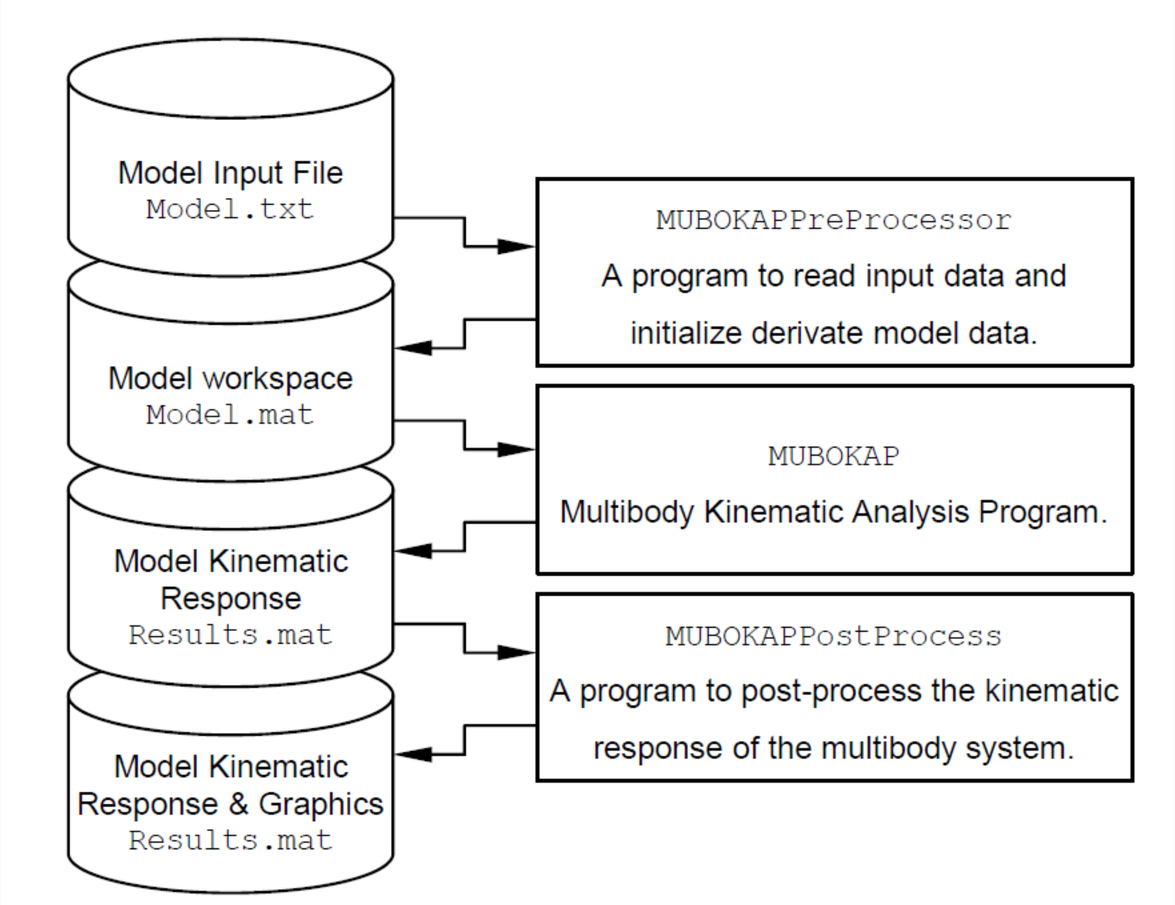
Dynamics of Mechanical Systems

2023/24

Summary

Kinematic analysis of mechanical systems using Cartesian Coordinates.
Application to a soccer kick using MuboKAP.

Dynamics of Mechanical Systems



The kinematic analysis program MUBOKAP has the same structure and methodological implementation as the first kinematic analysis program used before.

Dynamics of Mechanical Systems

<u>Input structure and Pre-Processor</u>

The modeling data and analysis profile is supplied to MuboKAP pre-processor via an ASCII text file (with the extension '.txt'). This input file is organized with the following structure:

Model dimensions (1st line): Information on the dimensions of the multibody system (data separated by space, tab, or comma), which includes, by order:

- NBody – Number of rigid bodies in the model
- NRevolute – Number of revolute joints
- NTranslation – Number of translation joints
- NRevRev – Number of composite revolute-revolute joints
- NTraRev – Number of composite revolute-translation joints
- NRigid – Number of rigid joints
- Dummy – Entry reserved for future developments (enter '0')
- NSimple – Number of simple joints
- NDriver – Number of driving constraints
- NPointsOfInt – Number of points of interest for reporting

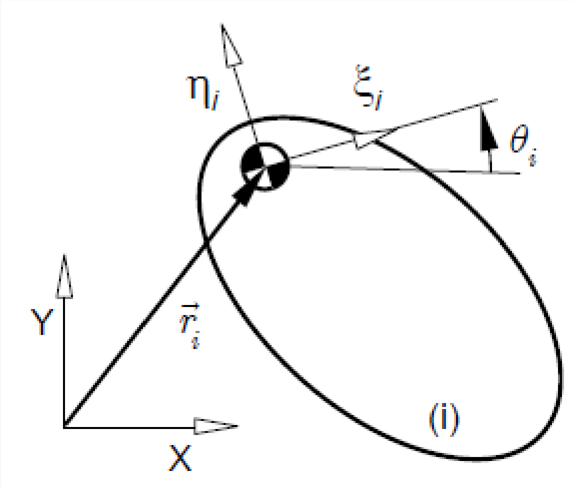
MuboKAP

Input structure and Pre-Processor

The next set of information consists in the rigid bodies estimated positions and orientations (for the definition of the initial position vector to be provided to Newton-Raphson). The input file must have one line for each rigid body with the following information:

Rigid bodies data (From lines 2 to NBody + 2): Information on the position and orientation of each of the rigid bodies of the model, which is constituted by:

- x_i – Position along X in the body fixed coordinate system
- y_i – Position along Y in the body fixed coordinate system
- θ_i – Angular orientation of the rigid body (in radians)

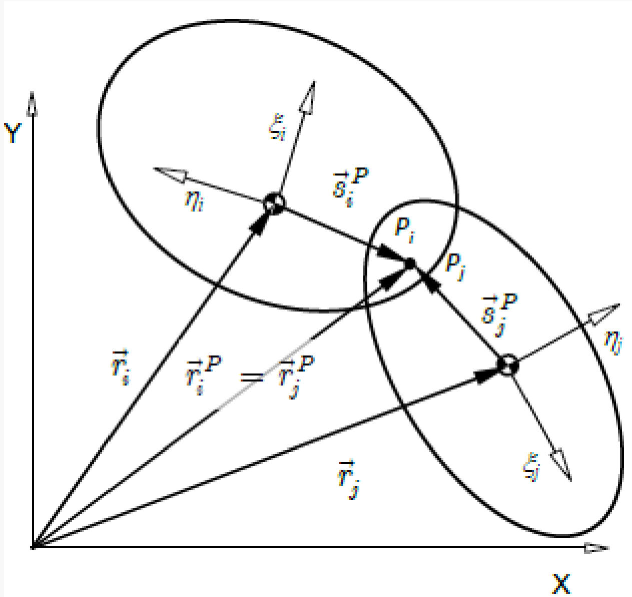


Dynamics of Mechanical Systems

Input structure and Pre-Processor

The next set of data concerns the information regarding the revolute joints. The required modelling data to be provided includes:

$$\mathbf{\Phi}^{(Rev,2)} = \mathbf{r}_i + \mathbf{A}_i \mathbf{s}_i'^P - \mathbf{r}_j - \mathbf{A}_j \mathbf{s}_j'^P$$



Revolute joints data (From lines Nbody + 3 to NBody + NRevolute + 3): Information on the rigid bodies of the model connected by the joint and location of the required geometric features:

- i – Number of the 1st body connected by the revolute joint
- j – Number of the 2nd body connected by the revolute joint
- ξ_i^P – ξ coordinate of point P in body i
- η_i^P – η coordinate of point P in body i
- ξ_j^P – ξ coordinate of point P in body j
- η_j^P – η coordinate of point P in body j

MuboKAP

Input structure and Pre-Processor

NBody NRevolute NTranslation NRevRev NTraRev Nrigid 0 Nsimple NDriver NPointsOfInt

…

After the description of all parameters from the 1st line, the last two lines address data regarding numerical methods and the time profile, respectively.

Numerical methods data (Line …): Information on numerical methods tolerances, which includes

- MaxIter – Maximum number of iterations for the nonlinear solvers
- Tolerance – Numerical tolerance for the solution of nonlinear equations

Time analysis profile data (Line …): Information on time period for the analysis and the reporting time step:

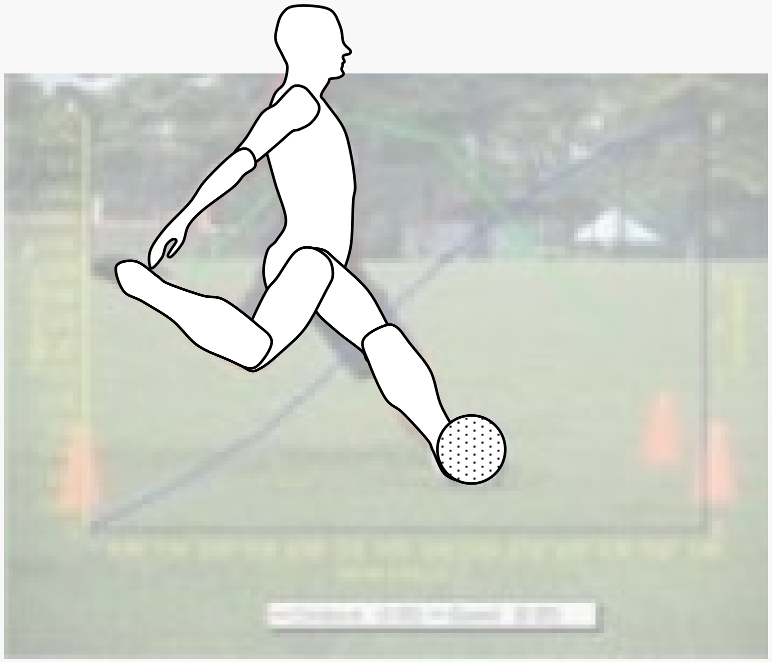
- TStart – Starting time for the kinematic analysis
- TStep – Time step for both analysis and reporting
- TEnd – Final time for the kinematic analysis

In the pre-processing stage, all data are assumed to be consistent, and all constraints are independent.

MuboKAP Application Case

Application case: Soccer kick

For the simulation of a soccer kick, a biomechanical model of the human body is developed. The shoulder, elbow, hip, and knee joints are simulated by revolute joints. The dimensions of the human body are obtained from anthropometric tables considering a height of 1.7 m.



Dynamics of Mechanical Systems

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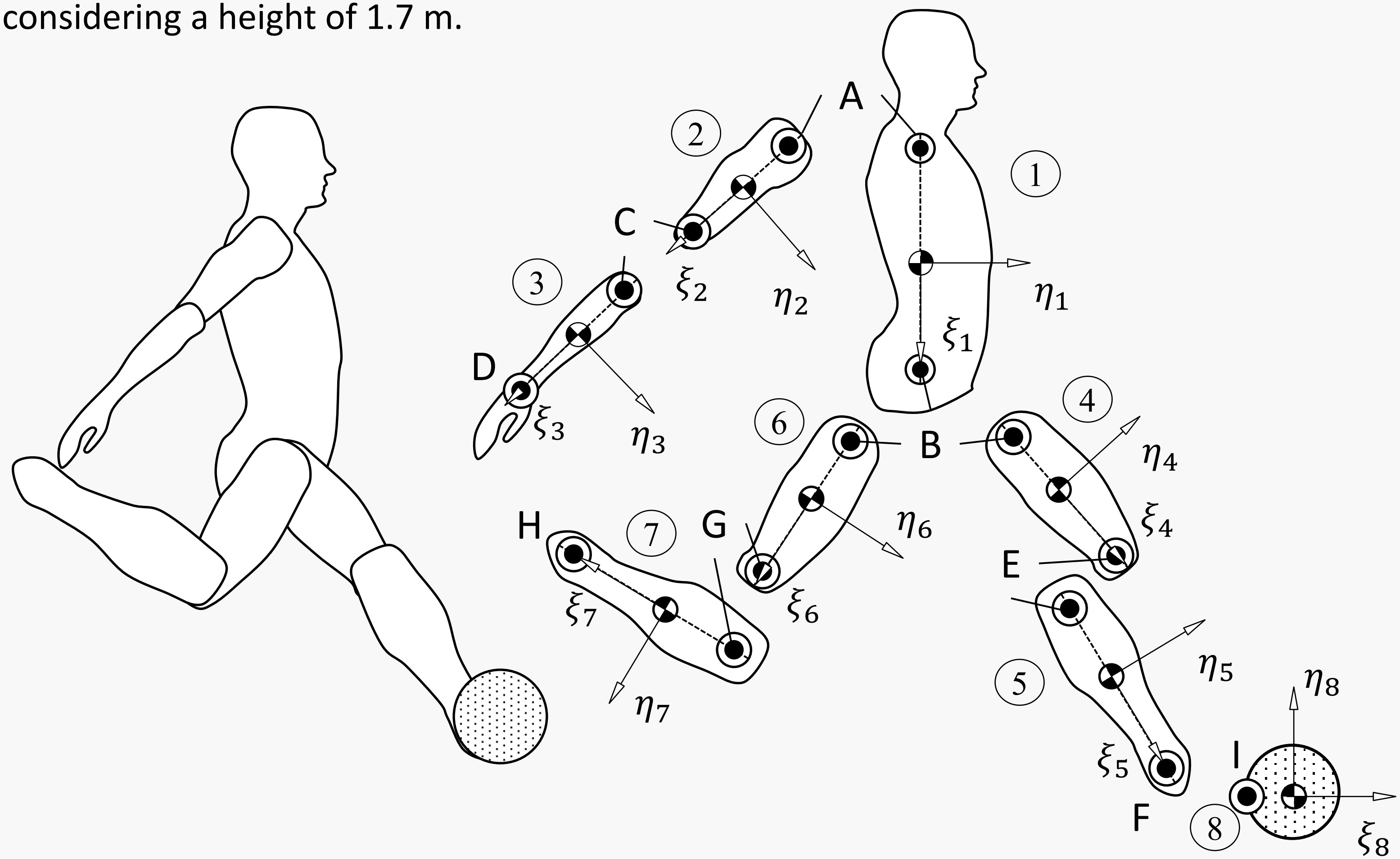


Application case: Soccer kick

For the simulation of a soccer kick, a biomechanical model of the human body is developed. The shoulder, elbow, hip, and knee joints are simulated by revolute joints. The dimensions of the human body are obtained from anthropometric tables considering a height of 1.7 m.

SEGMENT	MALES	FEMALES
Head and neck	10.75	10.75
Trunk	30.00	29.00
Upper arm	17.20	17.30
Forearm	15.70	16.00
Hand	5.75	5.75
Thigh	23.20	24.90
Lower leg	24.70	25.70
Foot	4.25	4.25

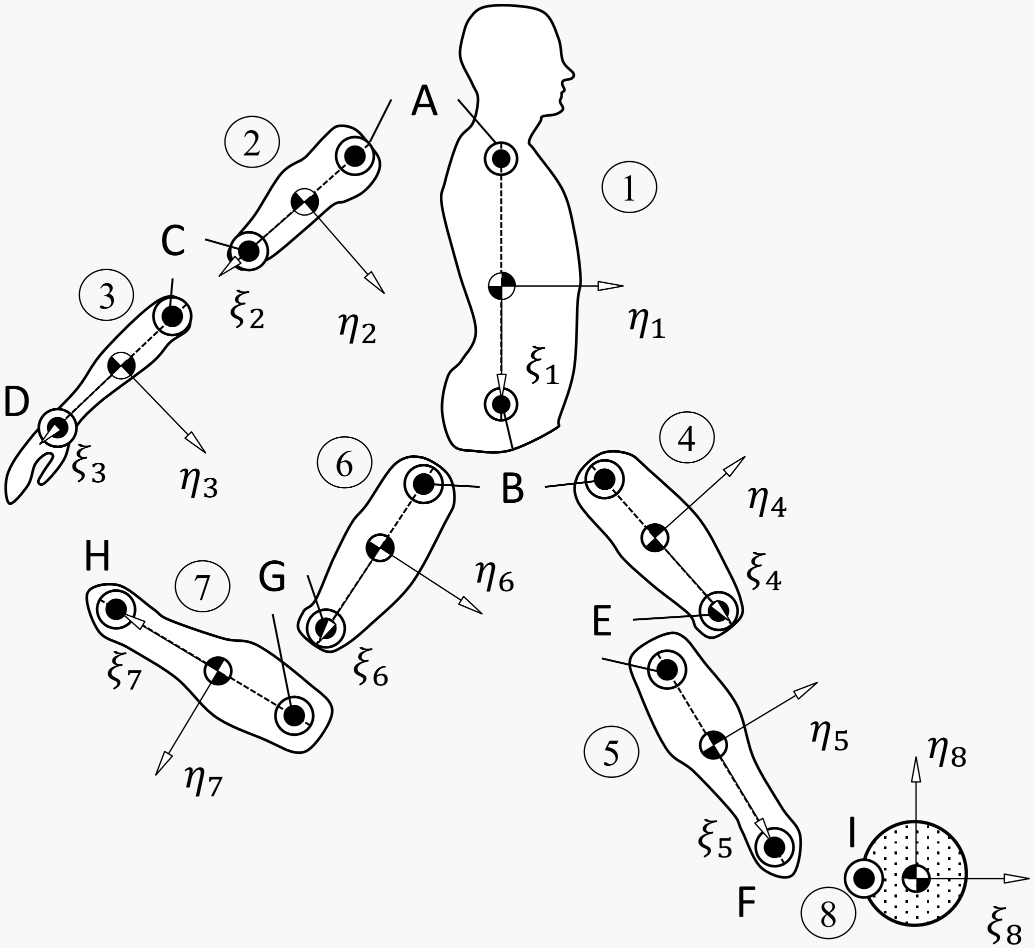
Segment lengths expressed in percentages of total body height.

Source: Susan Hall, Basic Biomechanics, Sixth Edition

<u>Application case: Soccer kick</u>

For the simulation of a soccer kick, a biomechanical model of the human body is developed. The shoulder, elbow, hip, and knee joints are simulated by revolute joints. The dimensions of the human body are obtained from anthropometric tables considering a height of 1.7 m.

$$l_{AB} = 0.51$$
$$l_{AC} = 0.29$$
$$l_{CD} = 0.27$$
$$l_{BE} = l_{BG} = 0.39$$
$$l_{EF} = l_{GH} = 0.42$$



MuboKAP Application Case

Application case: Soccer kick

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$$\mathbf{s}_1'^A = \begin{Bmatrix} -0.255 \\ 0.000 \end{Bmatrix} \quad \mathbf{s}_1'^B = \begin{Bmatrix} 0.255 \\ 0.000 \end{Bmatrix}$$

$$\mathbf{s}_2'^A = \begin{Bmatrix} -0.126 \\ 0.000 \end{Bmatrix} \quad \mathbf{s}_2'^C = \begin{Bmatrix} 0.164 \\ 0.000 \end{Bmatrix}$$

$$\mathbf{s}_3'^C = \begin{Bmatrix} -0.116 \\ 0.000 \end{Bmatrix} \quad \mathbf{s}_3'^D = \begin{Bmatrix} 0.154 \\ 0.000 \end{Bmatrix}$$

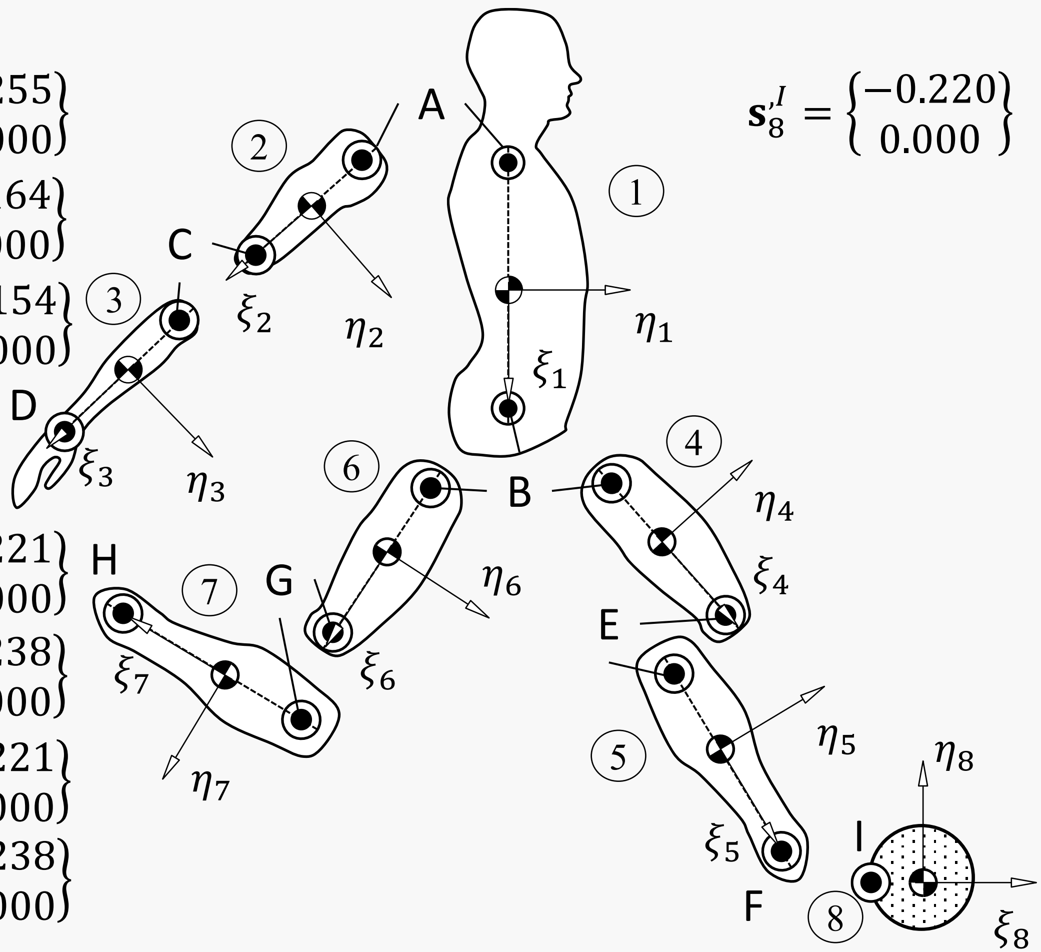
$$\mathbf{s}_4'^B = \begin{Bmatrix} -0.169 \\ 0.000 \end{Bmatrix} \quad \mathbf{s}_4'^E = \begin{Bmatrix} 0.221 \\ 0.000 \end{Bmatrix}$$

$$\mathbf{s}_5'^E = \begin{Bmatrix} -0.182 \\ 0.000 \end{Bmatrix} \quad \mathbf{s}_5'^F = \begin{Bmatrix} 0.238 \\ 0.000 \end{Bmatrix}$$

$$\mathbf{s}_6'^B = \begin{Bmatrix} -0.169 \\ 0.000 \end{Bmatrix} \quad \mathbf{s}_6'^G = \begin{Bmatrix} 0.221 \\ 0.000 \end{Bmatrix}$$

$$\mathbf{s}_7'^G = \begin{Bmatrix} -0.182 \\ 0.000 \end{Bmatrix} \quad \mathbf{s}_7'^H = \begin{Bmatrix} 0.238 \\ 0.000 \end{Bmatrix}$$

$$\mathbf{s}_8'^I = \begin{Bmatrix} -0.220 \\ 0.000 \end{Bmatrix}$$



Dynamics of Mechanical Systems

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Application case: Soccer kick

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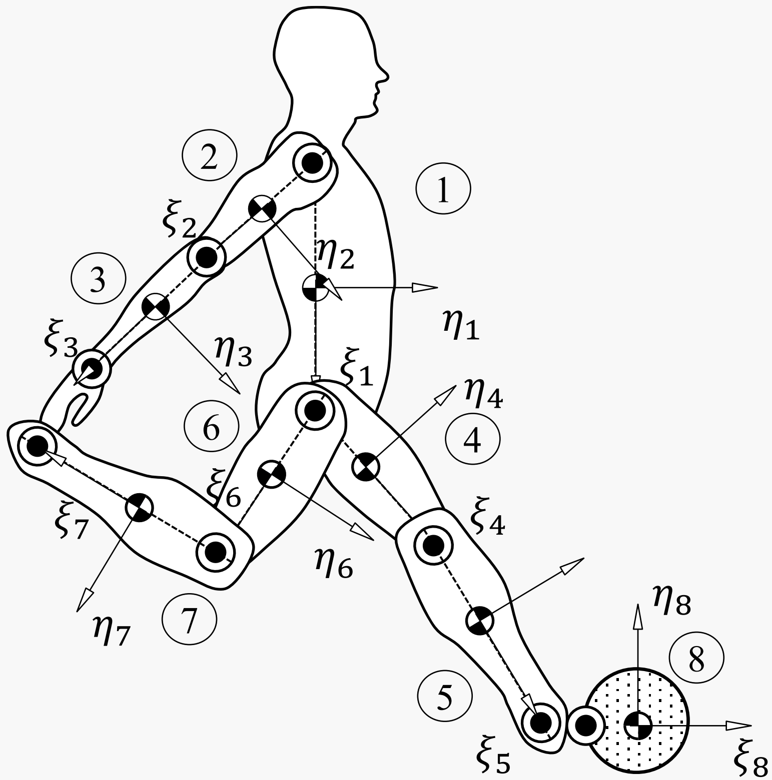

Input file:

8 NRevolute NTranslation NRevRev NTraRev Nrigid 0 Nsimple NDriver NPointsOfInt

Application case: Soccer kick

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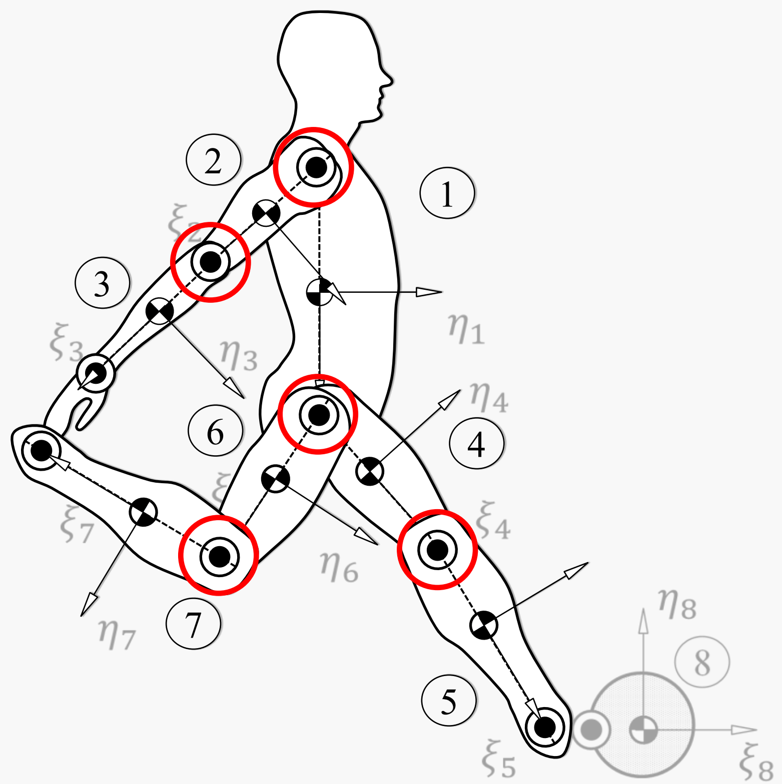

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Dynamics of Mechanical Systems

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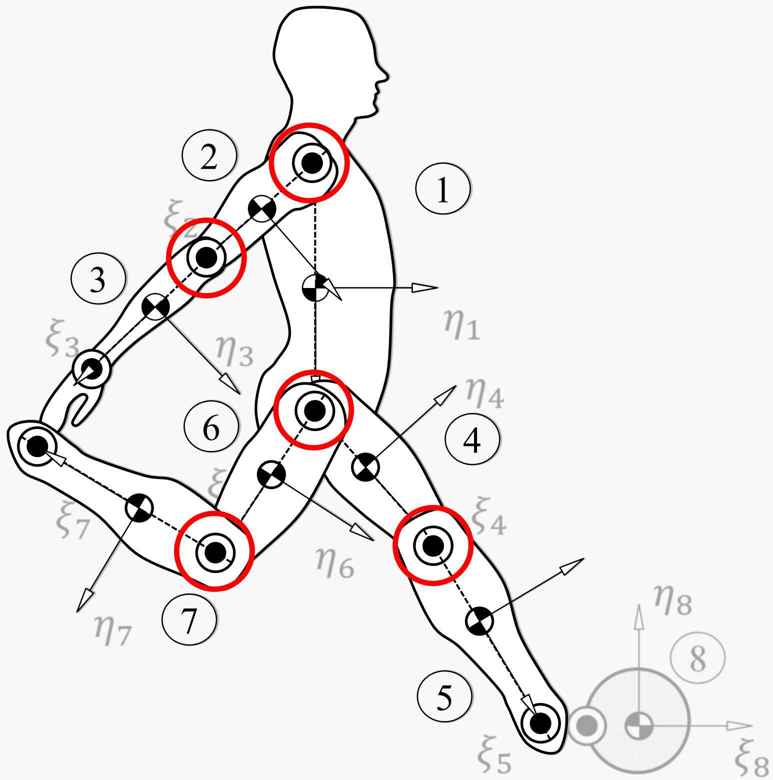

Input file:

8 6 NTranslation NRevRev NTraRev Nrigid 0 Nsimple NDriver NPointsOfInt

Application case: Soccer kick

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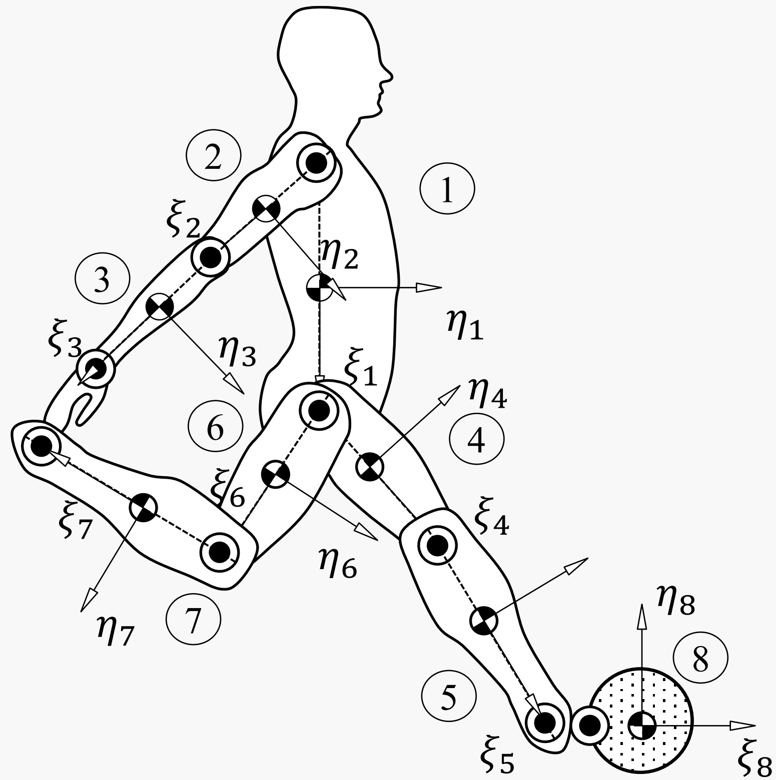

Input file:

8 6 0 0 0 0 0 0 NDriver NPointsOfInt

$$n_{dof} = 8 \times 3 - (6 \times 2) = 12$$

Dynamics of Mechanical Systems

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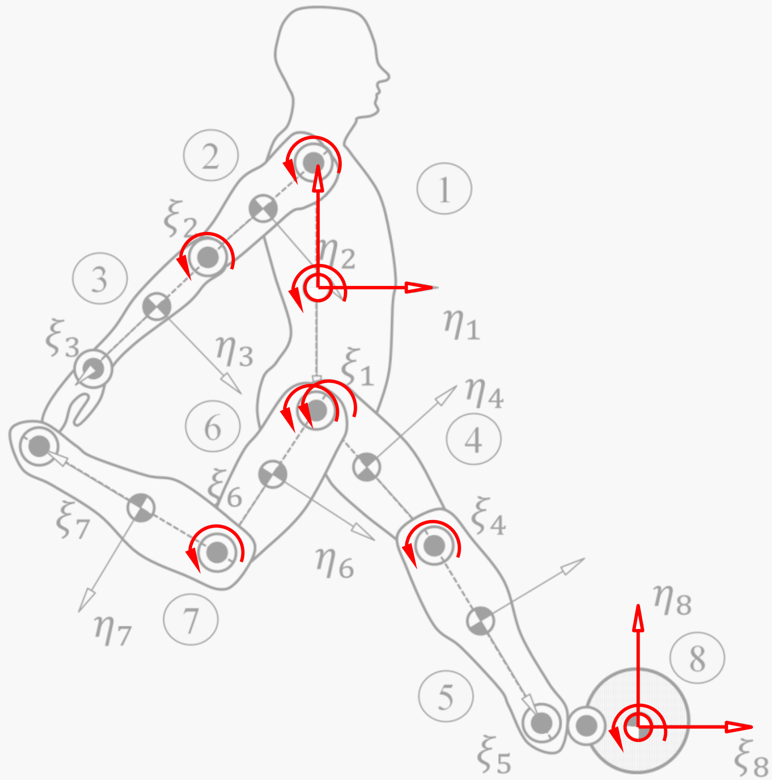

Input file:

8 6 0 0 0 0 0 0 NDriver NPointsOfInt

$$n_{dof} = 8 \times 3 - (6 \times 2) = 12$$

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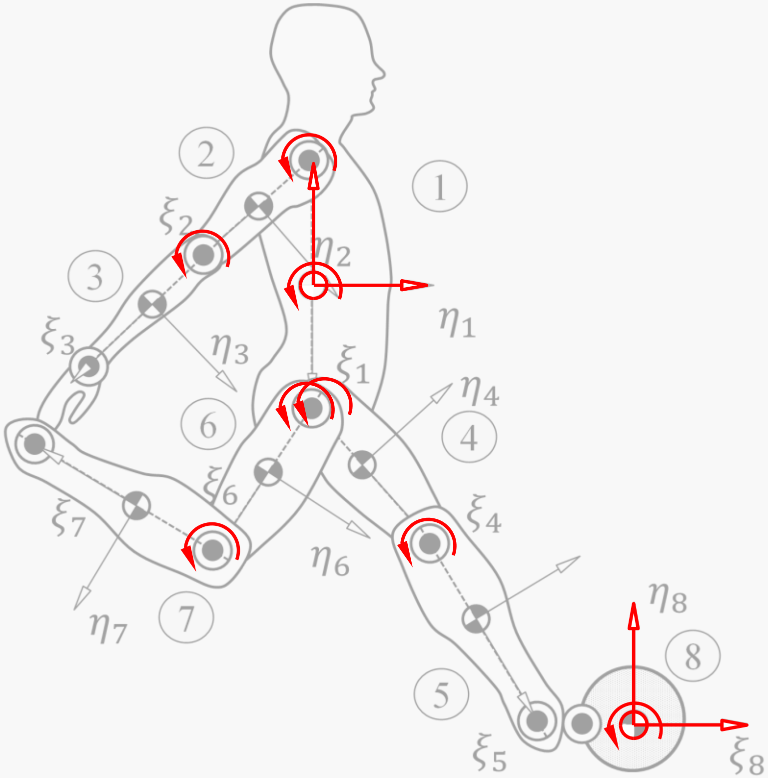


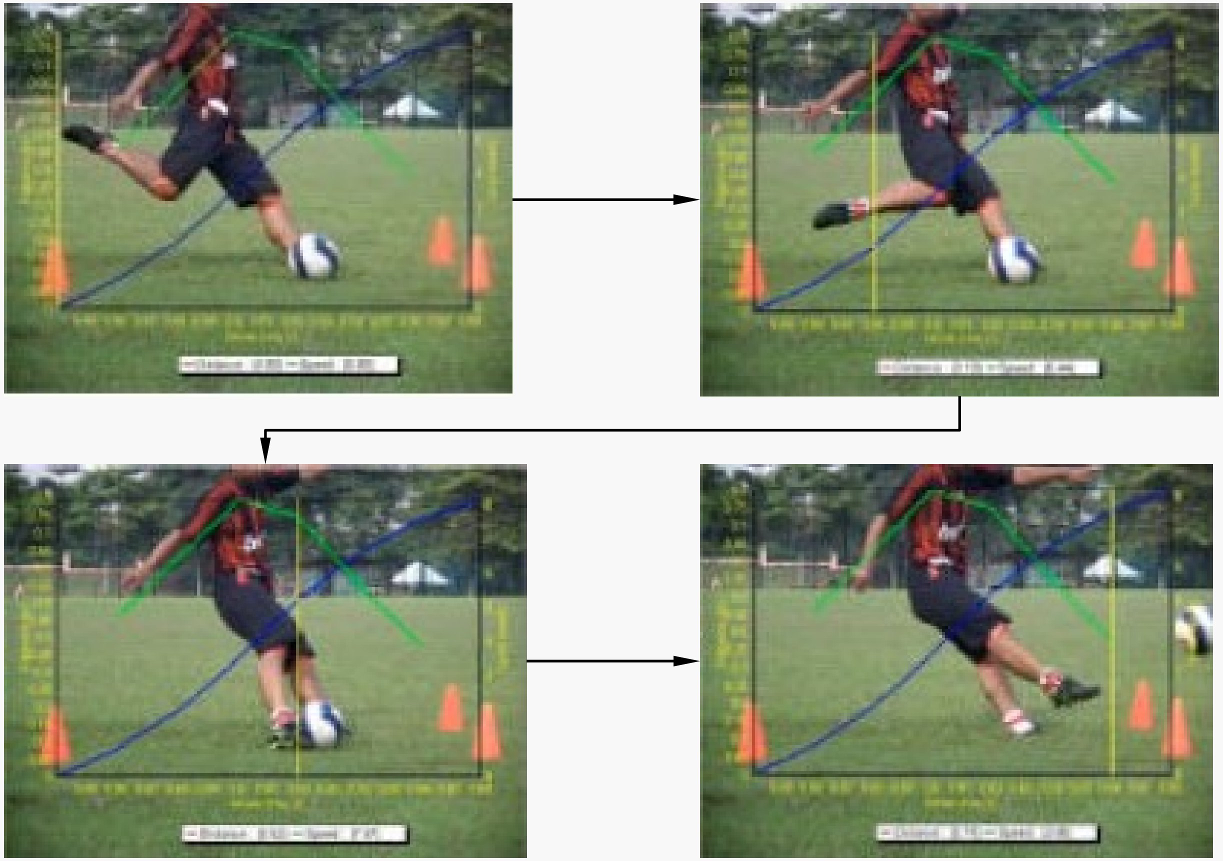
Input file:

8 6 0 0 0 0 0 0 12 0

Dynamics of Mechanical Systems

Application case: Soccer kick

For 2D motions, the initial position can be estimated from the first pose of the sequence of images of the motion to be studied.



Dynamics of Mechanical Systems

Application case: Soccer kick

$$\mathbf{r}_1 = \begin{Bmatrix} 0.64 \\ 1.05 \end{Bmatrix} \quad \theta_1 = 270°$$

$$\mathbf{r}_2 = \begin{Bmatrix} 0.54 \\ 1.21 \end{Bmatrix} \quad \theta_2 = 221°$$

$$\mathbf{r}_3 = \begin{Bmatrix} 0.34 \\ 1.01 \end{Bmatrix} \quad \theta_3 = 228°$$

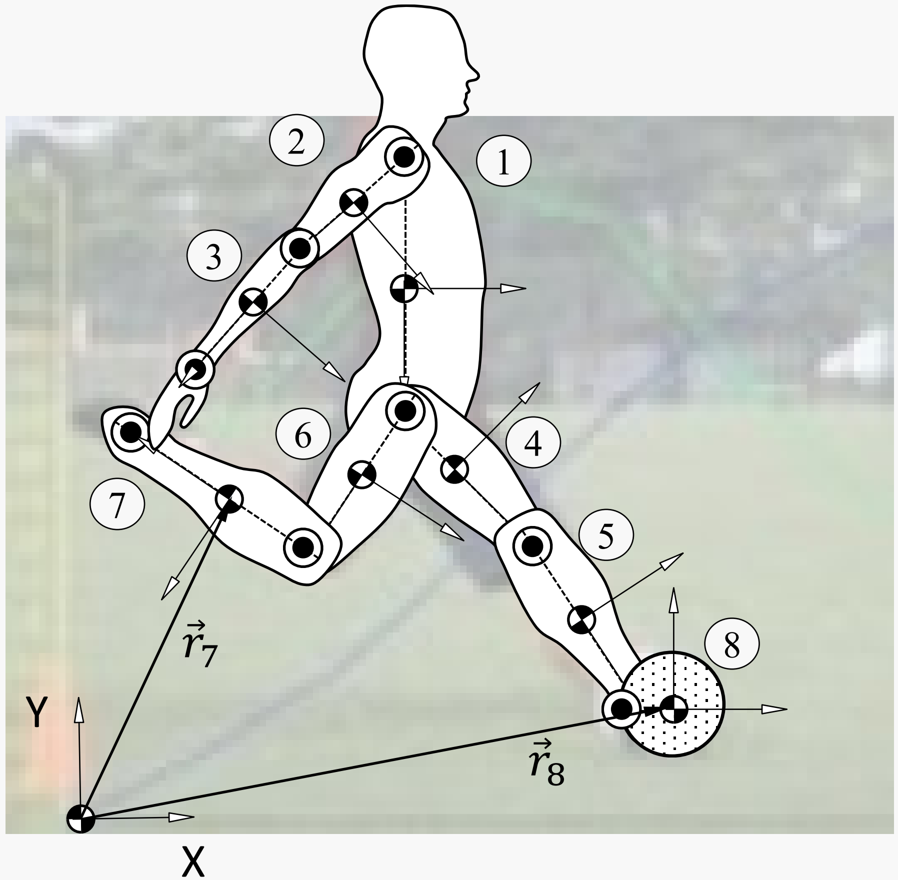
$$\mathbf{r}_4 = \begin{Bmatrix} 0.73 \\ 0.68 \end{Bmatrix} \quad \theta_4 = 315°$$

$$\mathbf{r}_5 = \begin{Bmatrix} 0.98 \\ 0.39 \end{Bmatrix} \quad \theta_5 = 304°$$

$$\mathbf{r}_6 = \begin{Bmatrix} 0.55 \\ 0.68 \end{Bmatrix} \quad \theta_6 = 236°$$

$$\mathbf{r}_7 = \begin{Bmatrix} 0.30 \\ 0.64 \end{Bmatrix} \quad \theta_7 = 146°$$

$$\mathbf{r}_8 = \begin{Bmatrix} 1.16 \\ 0.22 \end{Bmatrix} \quad \theta_8 = 0°$$



Application case: Soccer kick

Input file:

8	6	0	0	0	0	0	0	12	0
0.64	1.05	4.71							
0.54	1.21	3.86							
0.34	1.01	3.98							
0.73	0.68	5.50							
0.98	0.39	5.31							
0.55	0.68	4.12							
0.30	0.64	2.55							
1.16	0.22	0.00							

$$\mathbf{r}_1 = \begin{Bmatrix} 0.64 \\ 1.05 \end{Bmatrix} \quad \theta_1 = 270°$$

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$$\mathbf{r}_7 = \begin{Bmatrix} 0.30 \\ 0.64 \end{Bmatrix} \quad \theta_7 = 146°$$

$$\mathbf{r}_4 = \begin{Bmatrix} 0.73 \\ 0.68 \end{Bmatrix} \quad \theta_4 = 315°$$

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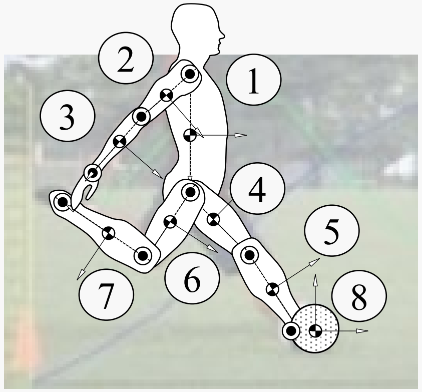


Dynamics of Mechanical Systems

Application case: Soccer kick

Input file:

8	6	0	0	0	0	0	0	12	0
0.64	1.05	4.71							
0.54	1.21	3.86							
0.34	1.01	3.98							
0.73	0.68	5.50							
0.98	0.39	5.31							
0.55	0.68	4.12							
0.30	0.64	2.55							
1.16	0.22	0.00							
1	2	-0.255	0.000	-0.126	0.000				
2	3	0.164	0.000	-0.116	0.000				
1	4	0.255	0.000	-0.169	0.000				
4	5	0.221	0.000	-0.182	0.000				
1	6	0.255	0.000	-0.169	0.000				
6	7	0.221	0.000	-0.182	0.000				

$$\mathbf{s}'^{A}_{1} = \begin{Bmatrix} -0.255 \\ 0.000 \end{Bmatrix} \quad \mathbf{s}'^{B}_{1} = \begin{Bmatrix} 0.255 \\ 0.000 \end{Bmatrix}$$

$$\mathbf{s}'^{A}_{2} = \begin{Bmatrix} -0.126 \\ 0.000 \end{Bmatrix} \quad \mathbf{s}'^{C}_{2} = \begin{Bmatrix} 0.164 \\ 0.000 \end{Bmatrix}$$

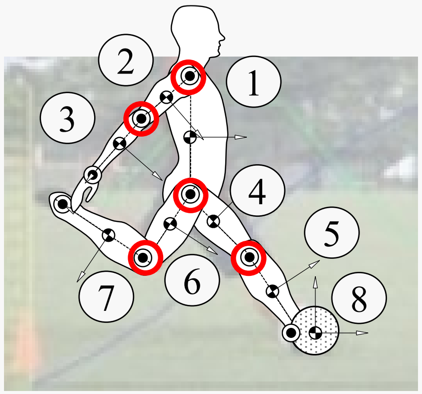
$$\mathbf{s}'^{C}_{3} = \begin{Bmatrix} -0.116 \\ 0.000 \end{Bmatrix} \quad \mathbf{s}'^{D}_{3} = \begin{Bmatrix} 0.154 \\ 0.000 \end{Bmatrix}$$

$$\mathbf{s}'^{B}_{4} = \begin{Bmatrix} -0.169 \\ 0.000 \end{Bmatrix} \quad \mathbf{s}'^{E}_{4} = \begin{Bmatrix} 0.221 \\ 0.000 \end{Bmatrix}$$

$$\mathbf{s}'^{E}_{5} = \begin{Bmatrix} -0.182 \\ 0.000 \end{Bmatrix} \quad \mathbf{s}'^{F}_{5} = \begin{Bmatrix} 0.238 \\ 0.000 \end{Bmatrix}$$

$$\mathbf{s}'^{B}_{6} = \begin{Bmatrix} -0.169 \\ 0.000 \end{Bmatrix} \quad \mathbf{s}'^{G}_{6} = \begin{Bmatrix} 0.221 \\ 0.000 \end{Bmatrix}$$

$$\mathbf{s}'^{G}_{7} = \begin{Bmatrix} -0.182 \\ 0.000 \end{Bmatrix} \quad \mathbf{s}'^{H}_{7} = \begin{Bmatrix} 0.238 \\ 0.000 \end{Bmatrix}$$

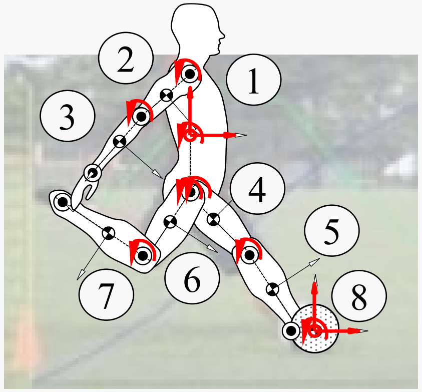


MuboKAP Application Case

Application case: Soccer kick

Input file:

```
8    6    0    0    0    0    0    0    12    0
0.64    1.05    4.71
0.54    1.21    3.86
0.34    1.01    3.98
0.73    0.68    5.50
0.98    0.39    5.31
0.55    0.68    4.12
0.30    0.64    2.55
1.16    0.22    0.00
1    2    -0.255    0.00    -0.126    0.00
2    3     0.164    0.00    -0.116    0.00
1    4     0.255    0.00    -0.169    0.00
4    5     0.221    0.00    -0.182    0.00
1    6     0.255    0.00    -0.169    0.00
6    7     0.221    0.00    -0.182    0.00
…
```



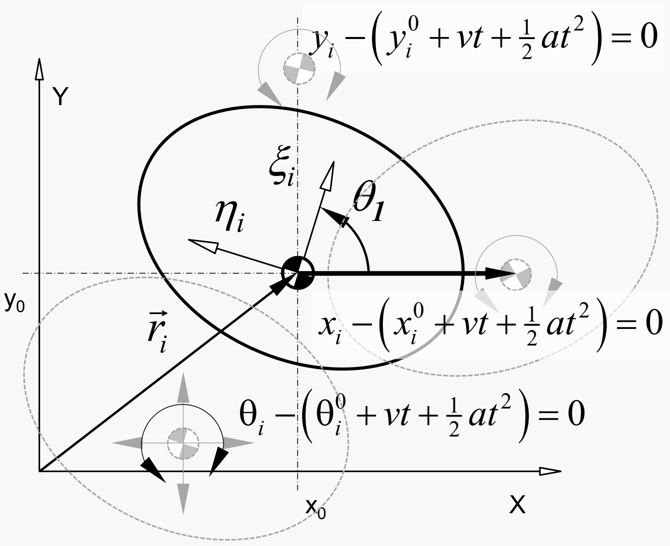
Dynamics of Mechanical Systems

Input structure and Pre-Processor

In addition to the simple and alternating driver, MuboKAP includes 3 additional types of drivers:

Type 3 (Driver for a single time-dependent coordinate with data read from a file)

$$\mathbf{\Phi}^{(dsg\quad,1)} = z_i - z(t)$$

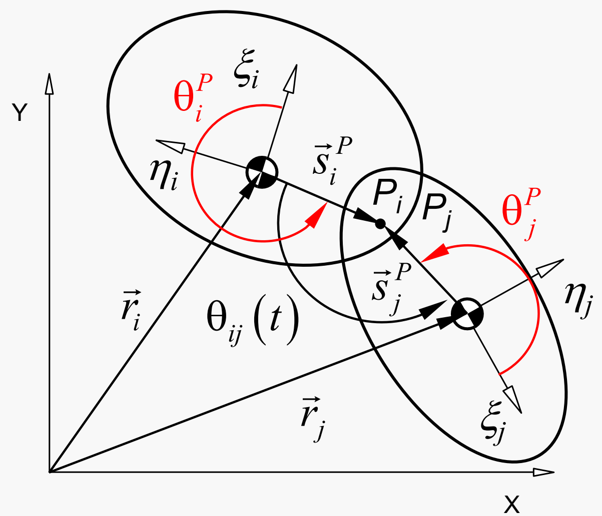


Input structure and Pre-Processor

In addition to the simple and alternating driver, MuboKAP includes 3 additional types of drivers:

Type 4 (Driver for the relative time-dependent orientation between two rigid bodies with data read from a file)

$$\mathbf{\Phi}^{(dang\quad,1)} = \theta_j - \theta_i - \theta_{ij}(t) - \theta_{ij}^{P^0}$$



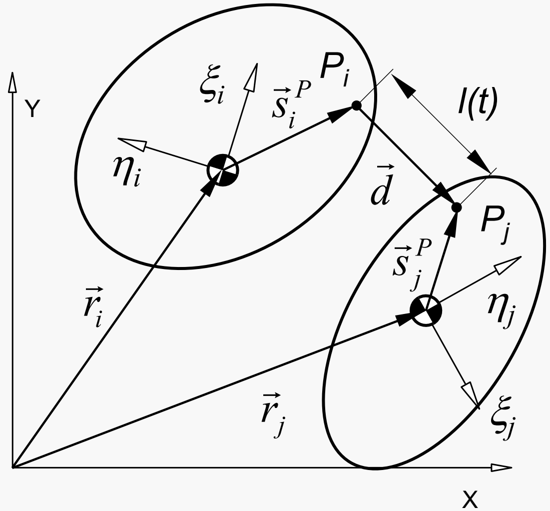
MuboKAP Application Case

Input structure and Pre-Processor

In addition to the simple and alternating driver, MuboKAP includes 3 additional types of drivers:

Type 5 (Driver for the relative time-dependent distance between two points with data read from a file)

$$\mathbf{\Phi}^{(dist\ \ ,1)} = \mathbf{d}^T\mathbf{d} - l(t)^2$$



Dynamics of Mechanical Systems

Input structure and Pre-Processor

The required modelling data to be provided includes:

- type – Type of driver joint
- i – Number of the 1st body driven
- coortype – Coordinate to be driven (either 1 (x), 2 (y), or 3 (θ))
- j – Number of the 2nd body driven
- ξ_i^P – ξ coordinate of point P in body i
- η_i^P – η coordinate of point P in body i
- ξ_j^P – ξ coordinate of point P in body j
- η_j^P – η coordinate of point P in body j
- order – order of the spline interpolation
- filename – number of the filename to be read

Driver types 3, 4, and 5, which read data from a file, require a text file with the time-dependent data. The name of the files should start with '**Driver_**'. For instance, if 'filename' is 1, MuboKAP will be looking for a file named 'Driver_001.txt'.

Dynamics of Mechanical Systems

Application case: Soccer kick

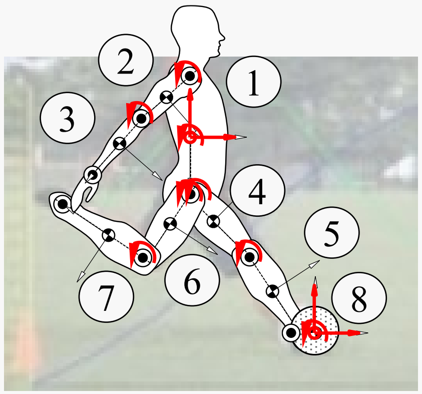
Input file:

8	6	0	0	0	0	0	0	12	0
0.64	1.05	4.71							
0.54	1.21	3.86							
0.34	1.01	3.98							
0.73	0.68	5.50							
0.98	0.39	5.31							
0.55	0.68	4.12							
0.30	0.64	2.55							
1.16	0.22	0.00							
1	2	-0.255	0.00	-0.126	0.00				
2	3	0.164	0.00	-0.116	0.00				
1	4	0.255	0.00	-0.169	0.00				
4	5	0.221	0.00	-0.182	0.00				
1	6	0.255	0.00	-0.169	0.00				
6	7	0.221	0.00	-0.182	0.00				

…

4	1	0	2	1.00	0.00	1.00	0.00	4	1
4	2	0	3	1.00	0.00	1.00	0.00	4	2
4	1	0	4	1.00	0.00	1.00	0.00	4	3
4	4	0	5	1.00	0.00	1.00	0.00	4	4
4	1	0	6	1.00	0.00	1.00	0.00	4	5
4	6	0	7	1.00	0.00	1.00	0.00	4	6
3	1	1	0	0.00	0.00	0.00	0.00	4	7
3	1	2	0	0.00	0.00	0.00	0.00	4	8
3	1	3	0	0.00	0.00	0.00	0.00	4	9
3	8	1	0	0.00	0.00	0.00	0.00	4	10
3	8	2	0	0.00	0.00	0.00	0.00	4	11
3	8	3	0	0.00	0.00	0.00	0.00	4	12

…



Input structure and Pre-Processor

The driver data file should describe how the degree of freedom to be driven changes with time:

0.00	-0.192
0.50	-0.280
1.00	-0.384
1.50	-0.628

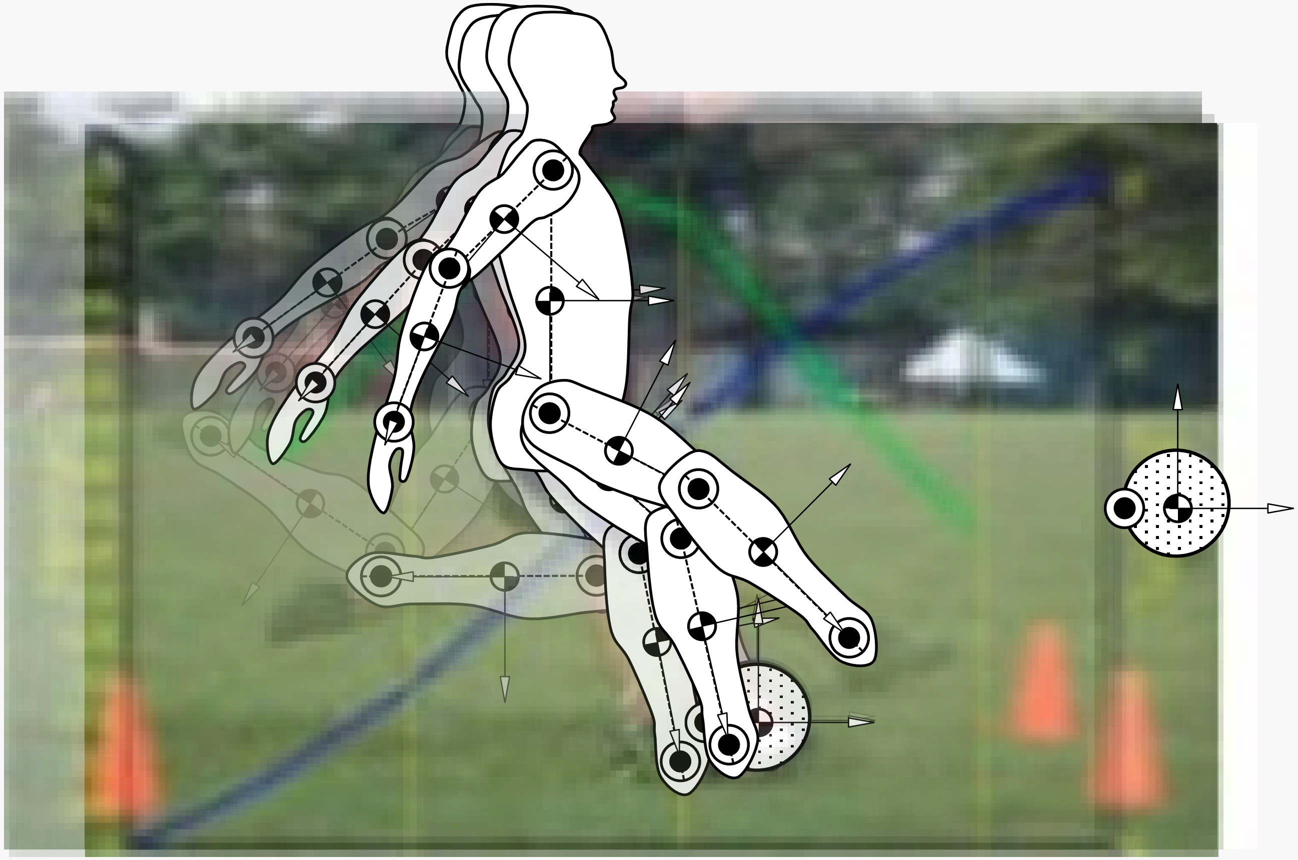
Time	Dof
t_0	z_0
$\dots$	$\dots$
t_f	z_f

Data will be interpolated using cubic or quintic splines to allow the evaluation of the degree of freedom for any time frame (within t_0 and t_f).

Dynamics of Mechanical Systems

Application case: Soccer kick

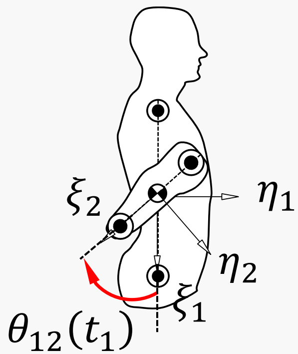
For 2D motions, data can be extracted from a sequence of images of a given motion.

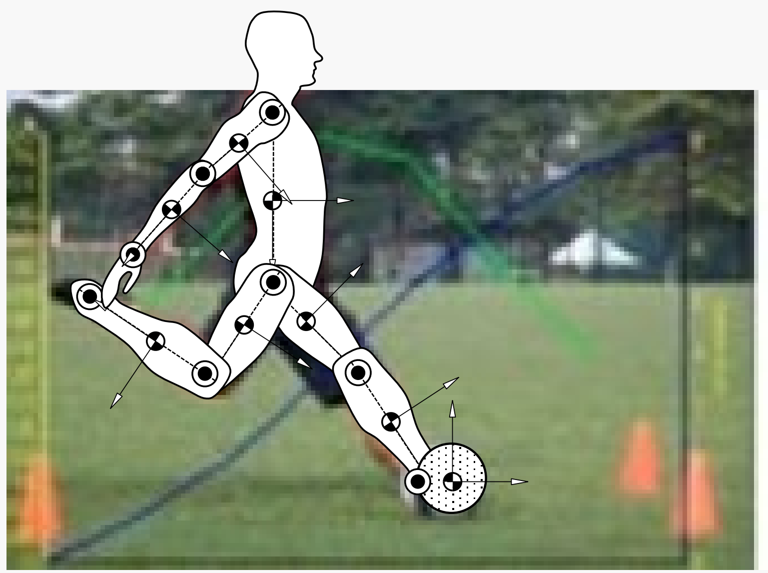


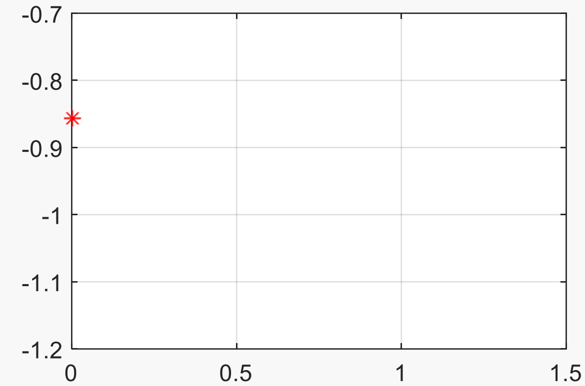
Dynamics of Mechanical Systems

<u>Application case: Soccer kick</u>

For 2D motions, data can be extracted from a sequence of images of a given motion.





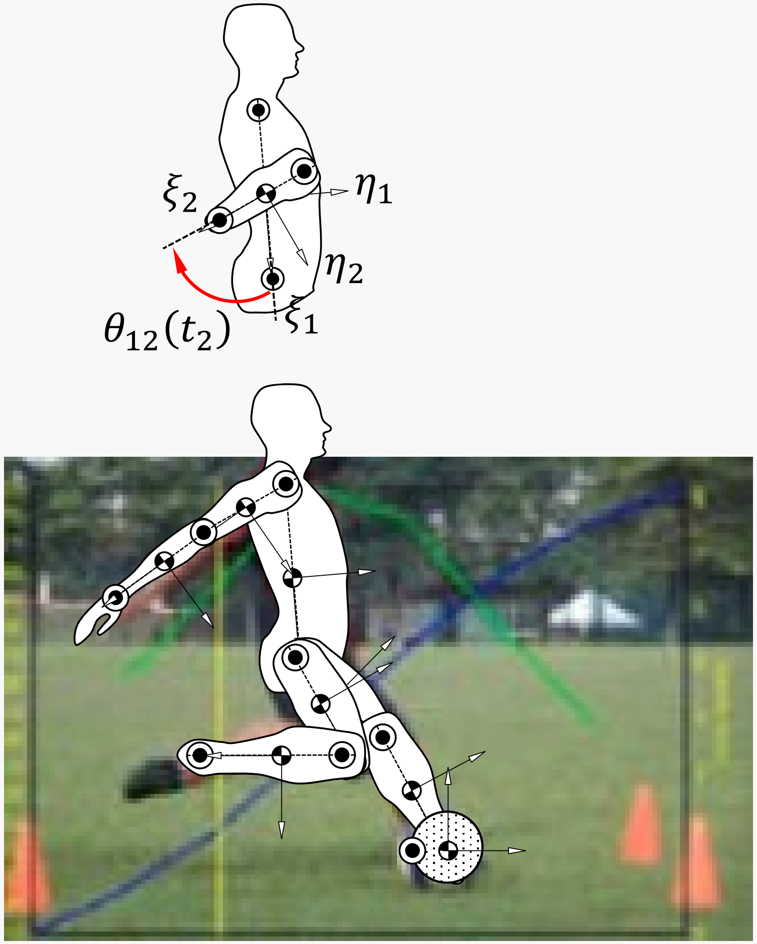


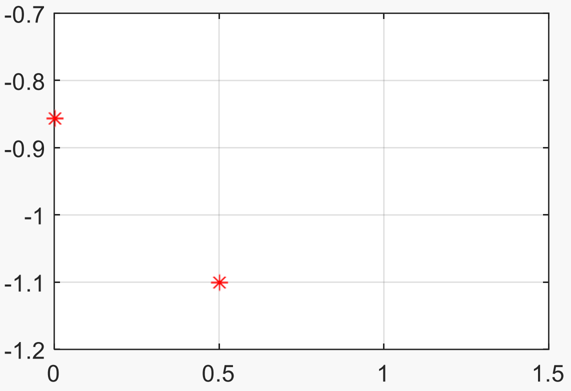
Time	Dof
t_1	$\theta_{12}(t_1) = -0.855$
t_2	
t_3	
t_4	

MuboKAP Application Case

<u>Application case: Soccer kick</u>

For 2D motions, data can be extracted from a sequence of images of a given motion.



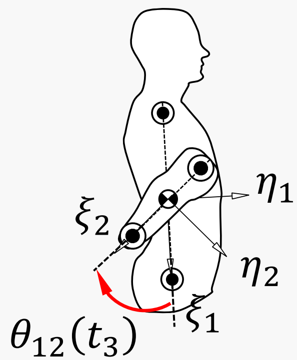


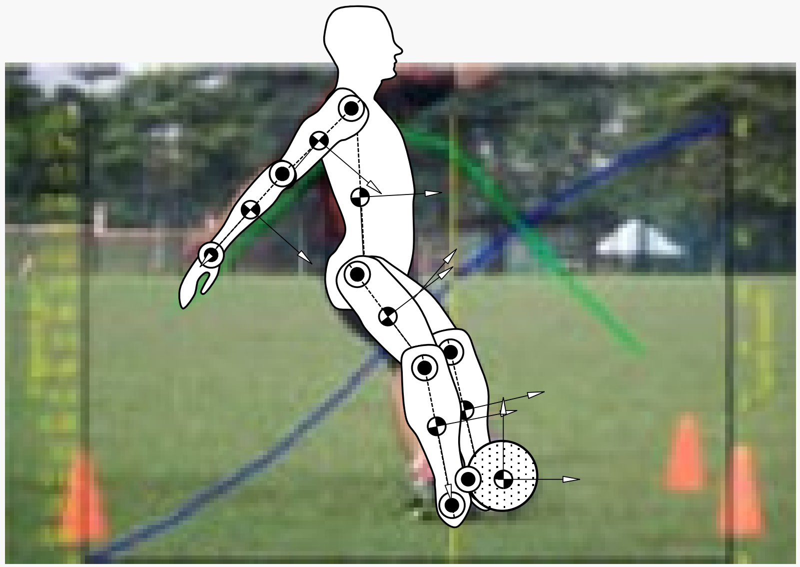
Time	Dof
t_1	$\theta_{12}(t_1) = -0.855$
t_2	$\theta_{12}(t_2) = -1.100$
t_3	
t_4	

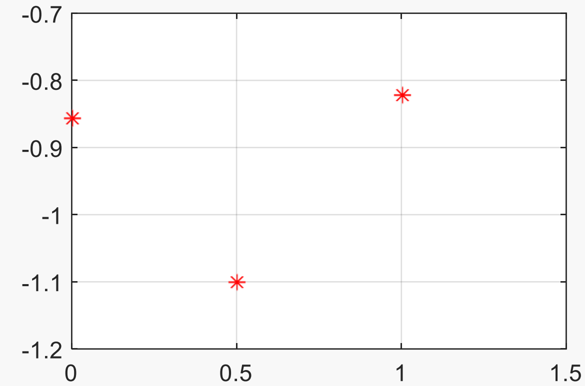
MuboKAP Application Case

Application case: Soccer kick

For 2D motions, data can be extracted from a sequence of images of a given motion.







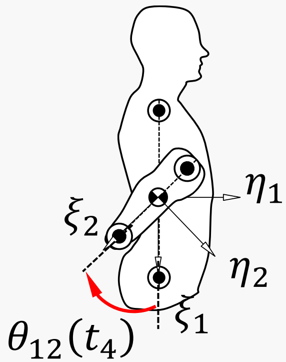
Time	Dof
t_1	$\theta_{12}(t_1) = -0.855$
t_2	$\theta_{12}(t_2) = -1.100$
t_3	$\theta_{12}(t_3) = -0.820$
t_4	

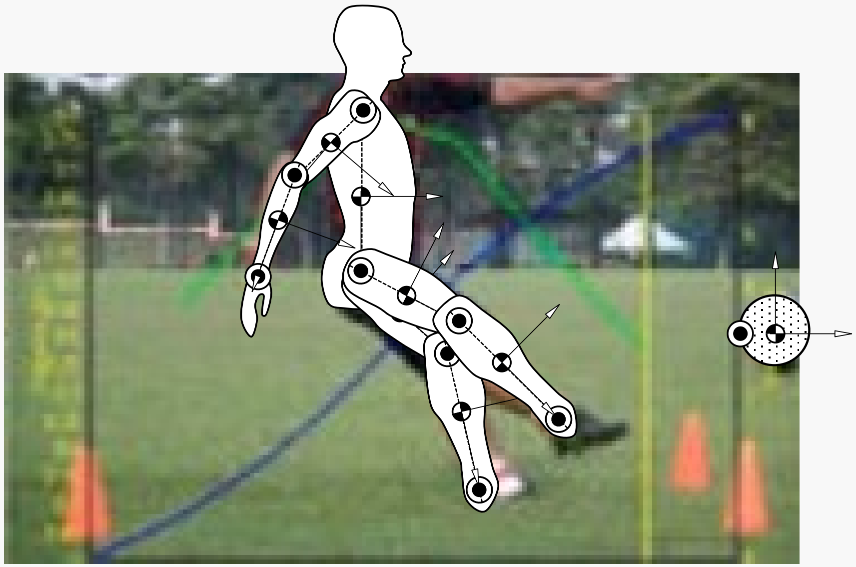
Dynamics of Mechanical Systems

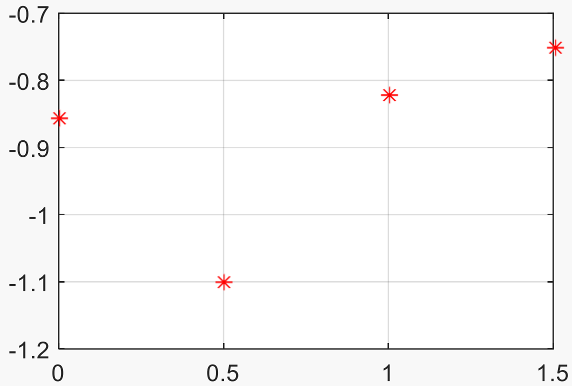
2023/24

<u>Application case: Soccer kick</u>

For 2D motions, data can be extracted from a sequence of images of a given motion.





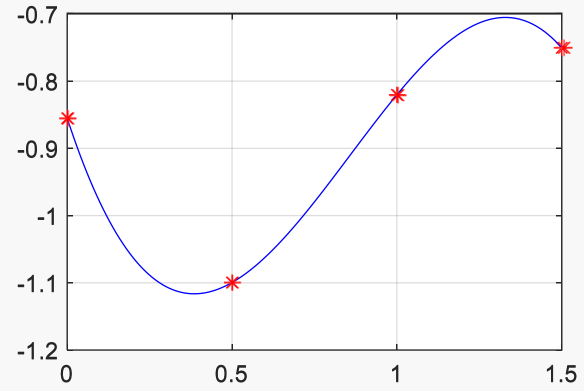


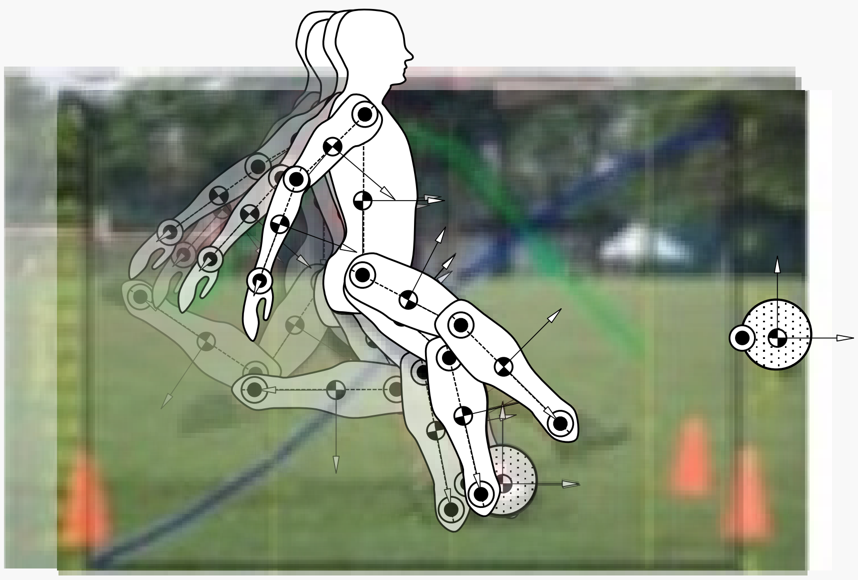
Time	Dof
t_1	$\theta_{12}(t_1) = -0.855$
t_2	$\theta_{12}(t_2) = -1.100$
t_3	$\theta_{12}(t_3) = -0.820$
t_4	$\theta_{12}(t_4) = -0.750$

MuboKAP Application Case

Application case: Soccer kick

For 2D motions, data can be extracted from a sequence of images of a given motion.





Time	Dof
t_1	$\theta_{12}(t_1) = -0.855$
t_2	$\theta_{12}(t_2) = -1.100$
t_3	$\theta_{12}(t_3) = -0.820$
t_4	$\theta_{12}(t_4) = -0.750$

Biomech.

<u>Note:</u>

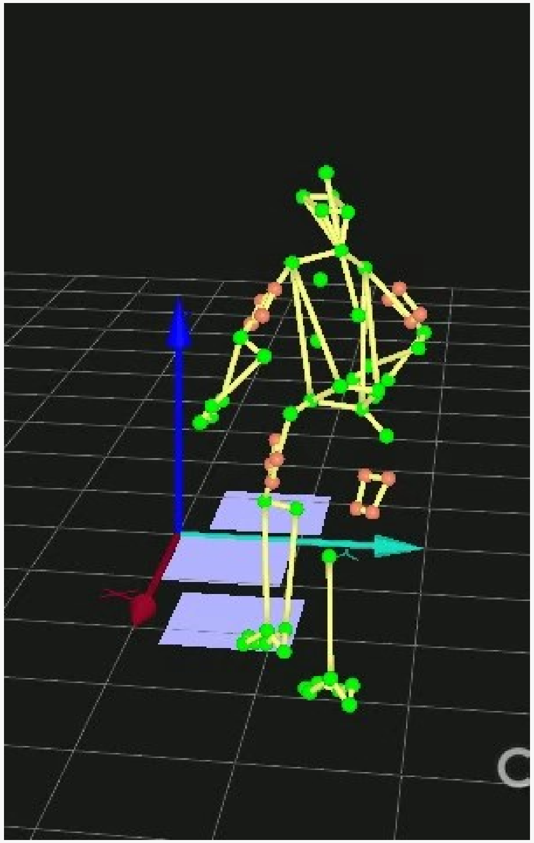
In biomechanics, human body motions are usually collected using motion capture systems that automatically reconstruct the 3D trajectories of relevant body points.

LbL
Laboratório de Biomecânica de Lisboa
Lisbon Biomechanics Laboratory

Biomech.

Note:

In biomechanics, human body motions are usually collected using motion capture systems that automatically reconstruct the 3D trajectories of relevant body points.



MuboKAP Application Case

Application case: Soccer kick

Input file:

8	6	0	0	0	0	0	0	12	0

0.64	1.05	4.71
0.54	1.21	3.86
0.34	1.01	3.98
0.73	0.68	5.50
0.98	0.39	5.31
0.55	0.68	4.12
0.30	0.64	2.55
1.16	0.22	0.00

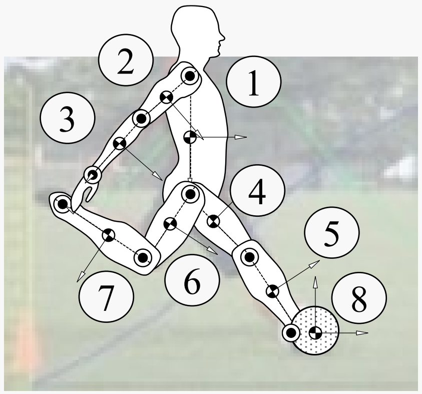
1	2	-0.255	0.00	-0.126	0.00
2	3	0.164	0.00	-0.116	0.00
1	4	0.255	0.00	-0.169	0.00
4	5	0.221	0.00	-0.182	0.00
1	6	0.255	0.00	-0.169	0.00
6	7	0.221	0.00	-0.182	0.00

…

4	1	0	2	1.00	0.00	1.00	0.00	4	1
4	2	0	3	1.00	0.00	1.00	0.00	4	2
4	1	0	4	1.00	0.00	1.00	0.00	4	3
4	4	0	5	1.00	0.00	1.00	0.00	4	4
4	1	0	6	1.00	0.00	1.00	0.00	4	5
4	6	0	7	1.00	0.00	1.00	0.00	4	6
3	1	1	0	0.00	0.00	0.00	0.00	4	7
3	1	2	0	0.00	0.00	0.00	0.00	4	8
3	1	3	0	0.00	0.00	0.00	0.00	4	9
3	8	1	0	0.00	0.00	0.00	0.00	4	10
3	8	2	0	0.00	0.00	0.00	0.00	4	11
3	8	3	0	0.00	0.00	0.00	0.00	4	12

12 0.0000001

0.000 0.010 1.500



MuboKAP Application Case

Application case: Soccer kick

Driver_001.txt

0.0	-0.855211333
0.5	-1.099557429
1.0	-0.820304748
1.5	-0.750491578

Driver_002.txt

0.0	0.122173048
0.5	0.104719755
1.0	0.017453293
1.5	0.453785606

Driver_003.txt

0.0	0.785398163
0.5	0.715584993
1.0	0.558505361
1.5	0.855211333

Driver_004.txt

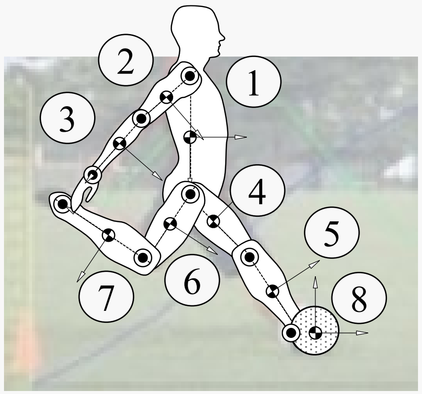
0.0	-0.191986218
0.5	-0.27925268
1.0	-0.383972435
1.5	-0.628318531

Driver_005.txt

0.0	-0.593411946
0.5	0.471238898
1.0	0.593411946
1.5	1.099557429

Driver_006.txt

0.0	-1.570796327
0.5	-2.111848395
1.0	-0.436332313
1.5	-0.296705973



Dynamics of Mechanical Systems

MuboKAP Application Case

Application case: Soccer kick

Driver_007.txt

0.0 0.636754386
0.5 0.724736842
1.0 0.748596491
1.5 0.75754386

Driver_008.txt

0.0 1.046842105
0.5 1.015526316
1.0 1.046842105
1.5 1.042368421

Driver_009.txt

0.0 4.71238898
0.5 4.78220215
1.0 4.764748858
1.5 4.71238898

Driver_010.txt

0.0 1.160175439
0.5 1.160175439
1.0 1.160175439
1.5 1.966929825

Driver_011.txt

0.0 0.222192982
0.5 0.222192982
1.0 0.222192982
1.5 0.632280702

Driver_012.txt

0.0 0.000
0.5 0.000
1.0 0.000
1.5 0.000