Musculoskeletal modeling of the swimming salamander

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Content

- Motivation
- Questions
- Modeling
- Robotics constraints and solutions
- Optimization
- Results
- Improvements
- Robot implementation and problems
- Future Works

Motivation

Understanding the role of muscles during swimming

Questions

What is the simplest model able to reproduce:

- the kinematics of the animal

- the interaction between muscle stimulation and body dynamics

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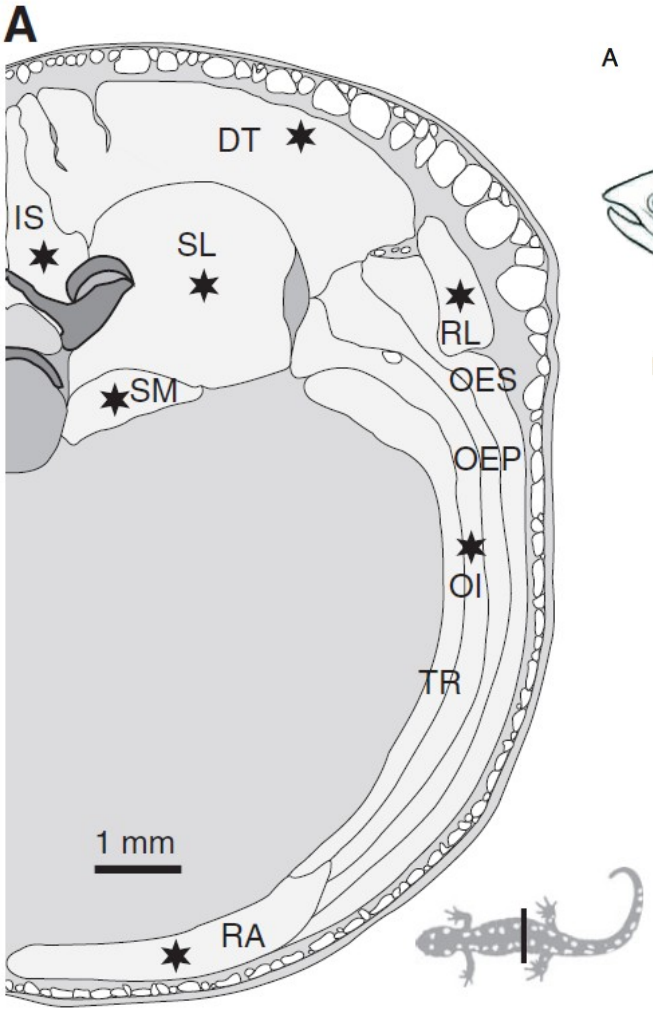
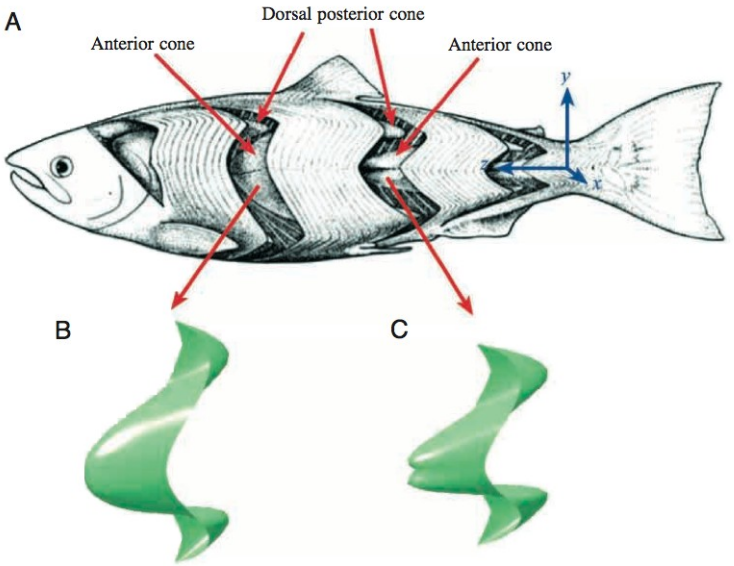
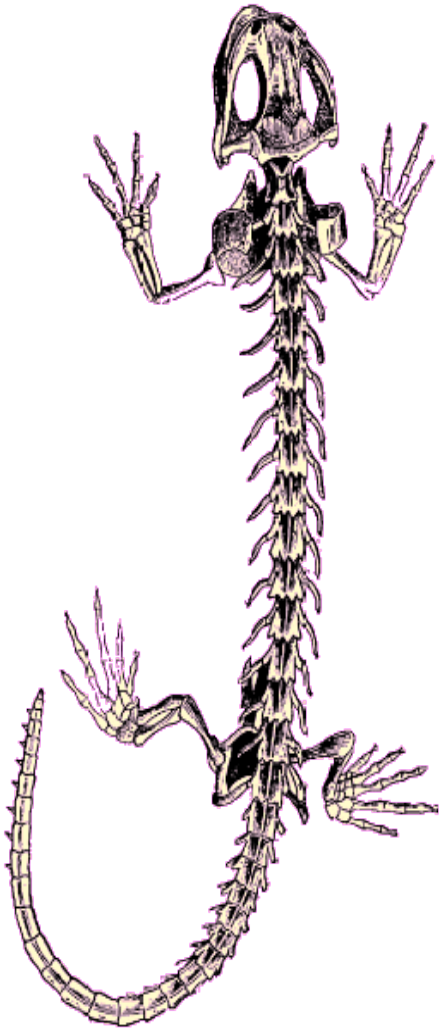
Morphology

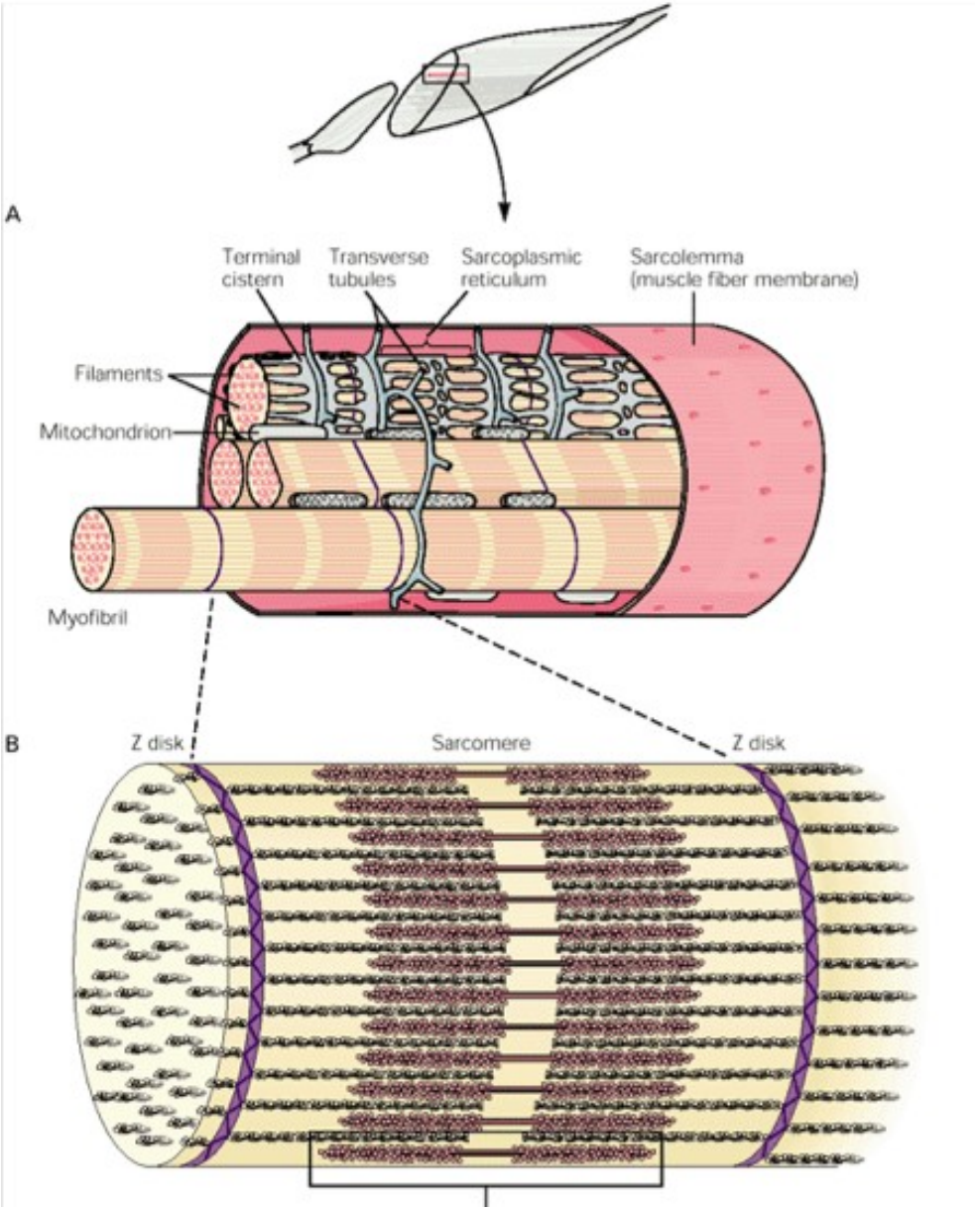




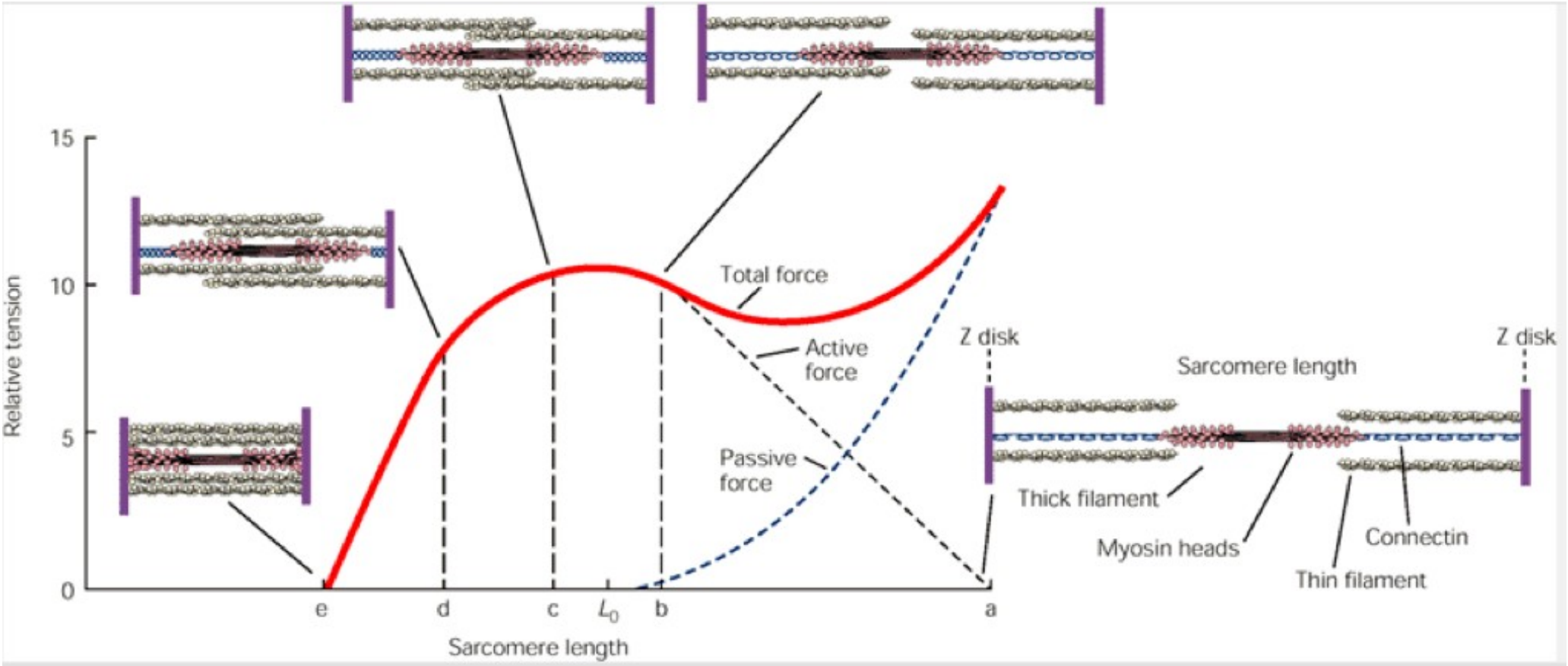
DT	m. dorsalis trunci
IS	m. interspinalis
OEP	m. obliquus externus profundus
OES	m. obliquus externus superficialis
OI	m. obliquus internus
RL	m. rectus lateralis
RA	m. rectus abdominis
SL	m. subvertebralis pars lateralis
SM	m. subvertebralis pars medialis
TA	m. transversus abdominis



Muscles

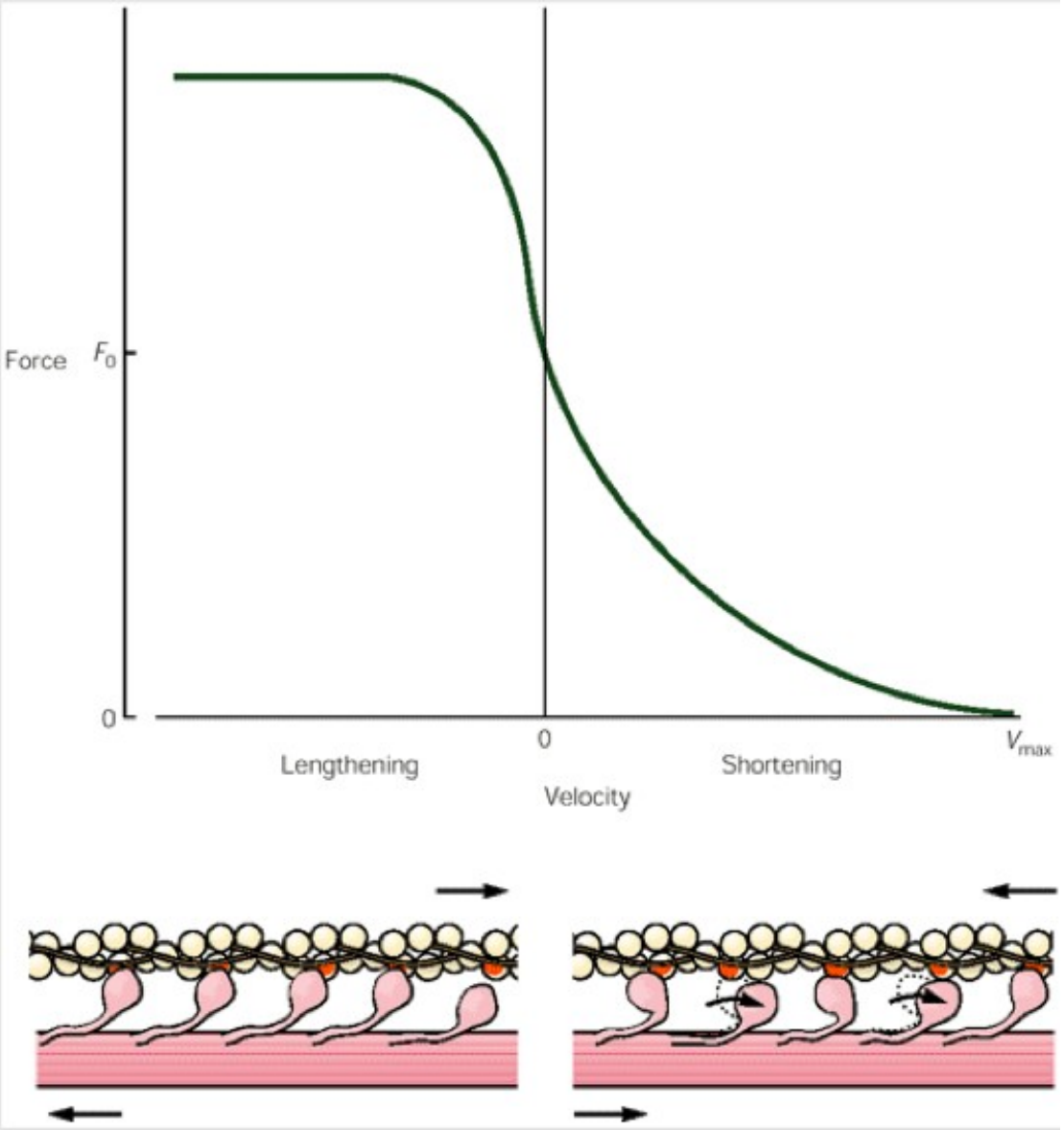

A
Terminal cistern
Transverse tubules
Sarcoplasmic reticulum
Sarcolemma (muscle fiber membrane)
Filaments
Mitochondrion
Myofibril
B
Z disk
Sarcomere
Z disk

Muscles



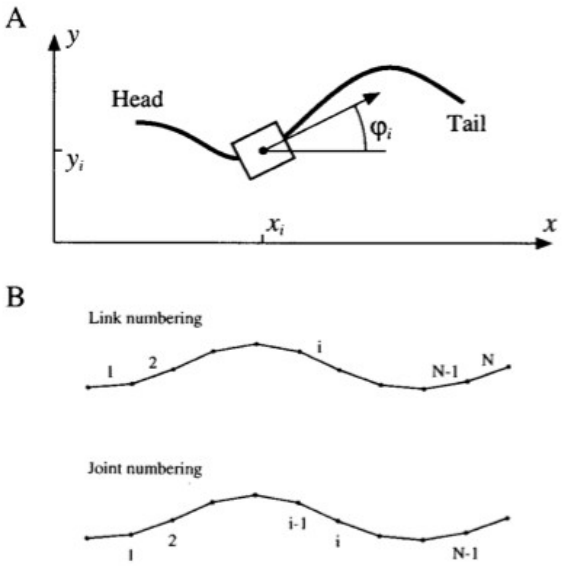
References :
G.E.Loeb, C.Ghez, Principles of Neural Science, chapter 34

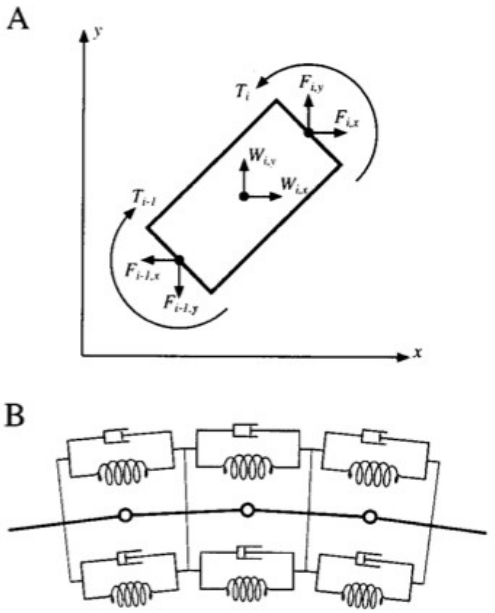
Muscles

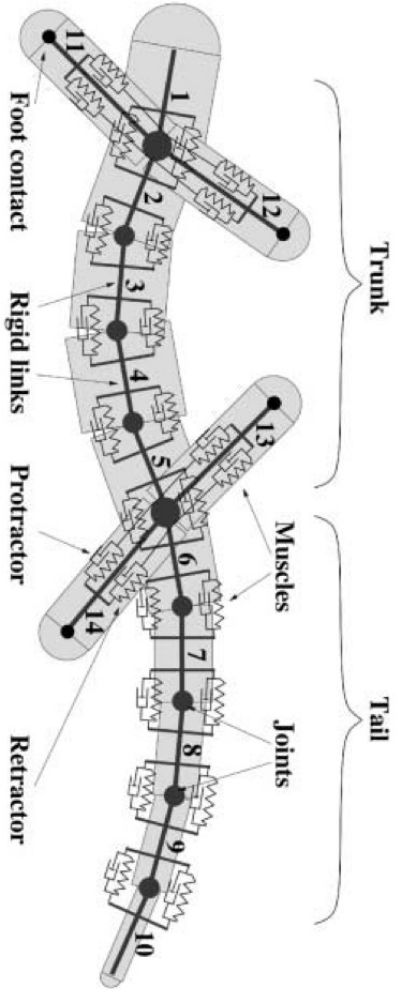


Previous Works

Reference :
A combined neuronal and mechanical model of fish swimming
O. Ekeberg 1993



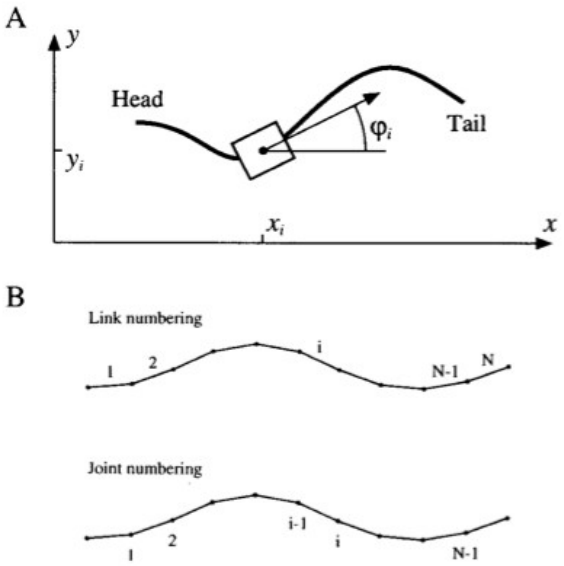


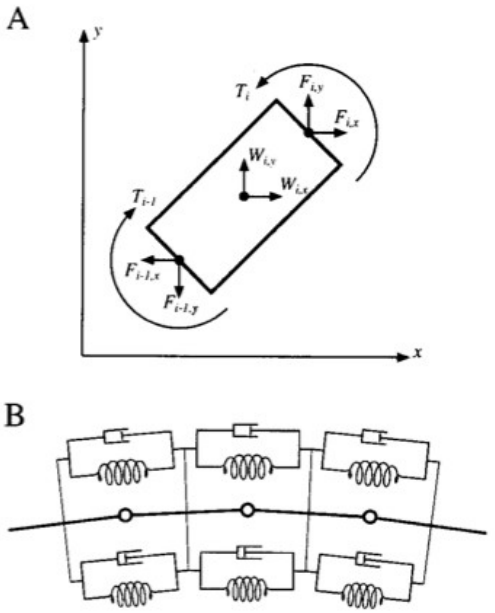


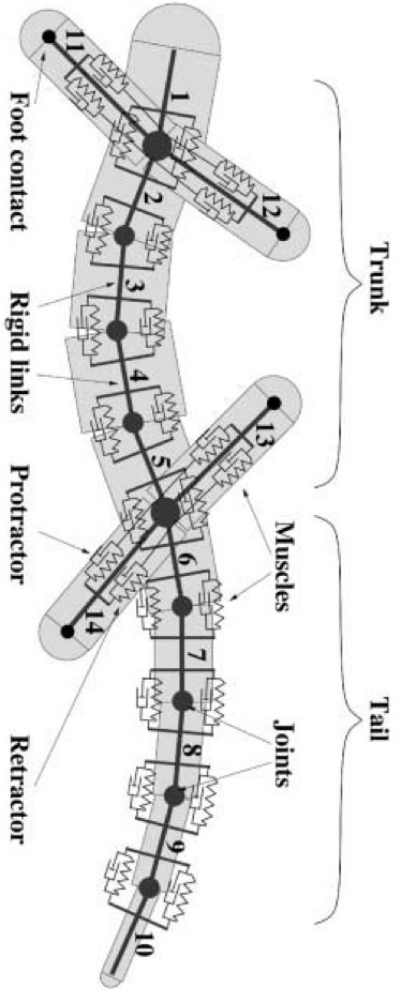
Reference :
A connectionist central pattern generator for the aquatic and terrestrial gaits of simulated salamander
A. J. Ijspeert 2000

State of the art

Reference :
A combined neuronal and mechanical model of fish swimming
O. Ekeberg 1993



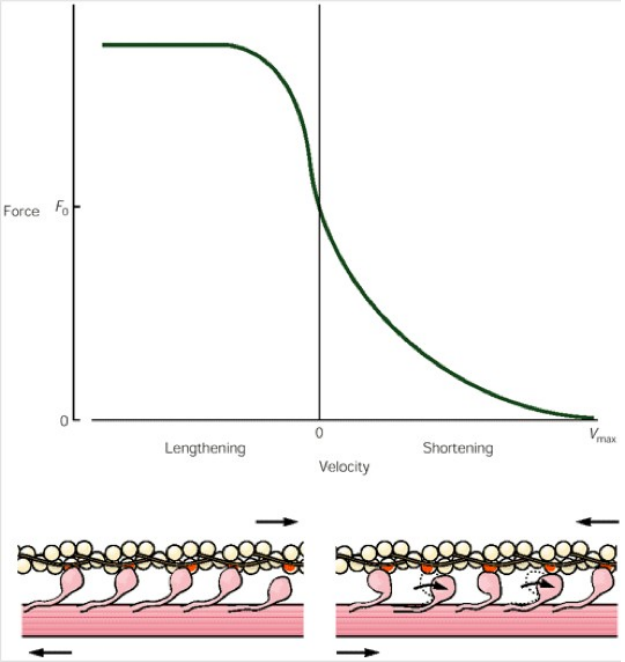




Reference :
A connectionist central pattern generator for the aquatic and terrestrial gaits of simulated salamander
A. J. Ijspeert 2000

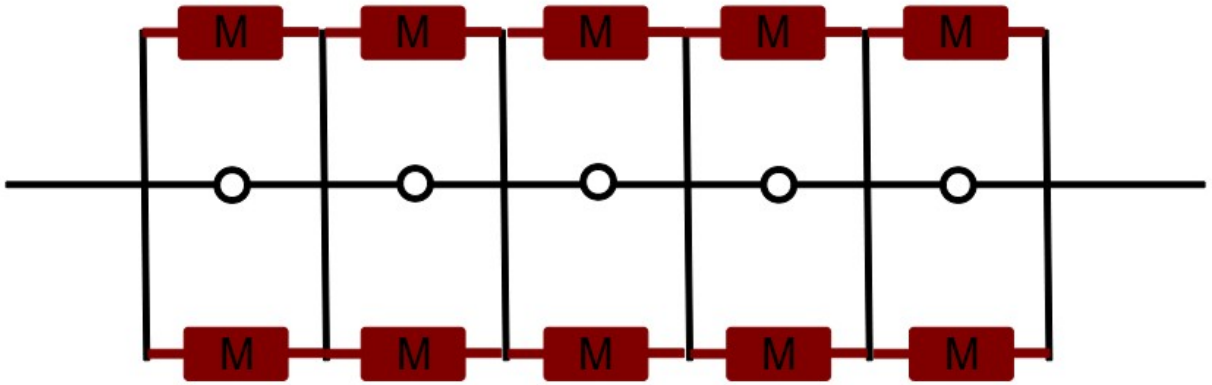
What is new and Why ?

Non Linear Muscle Model → Force(Speed) relation

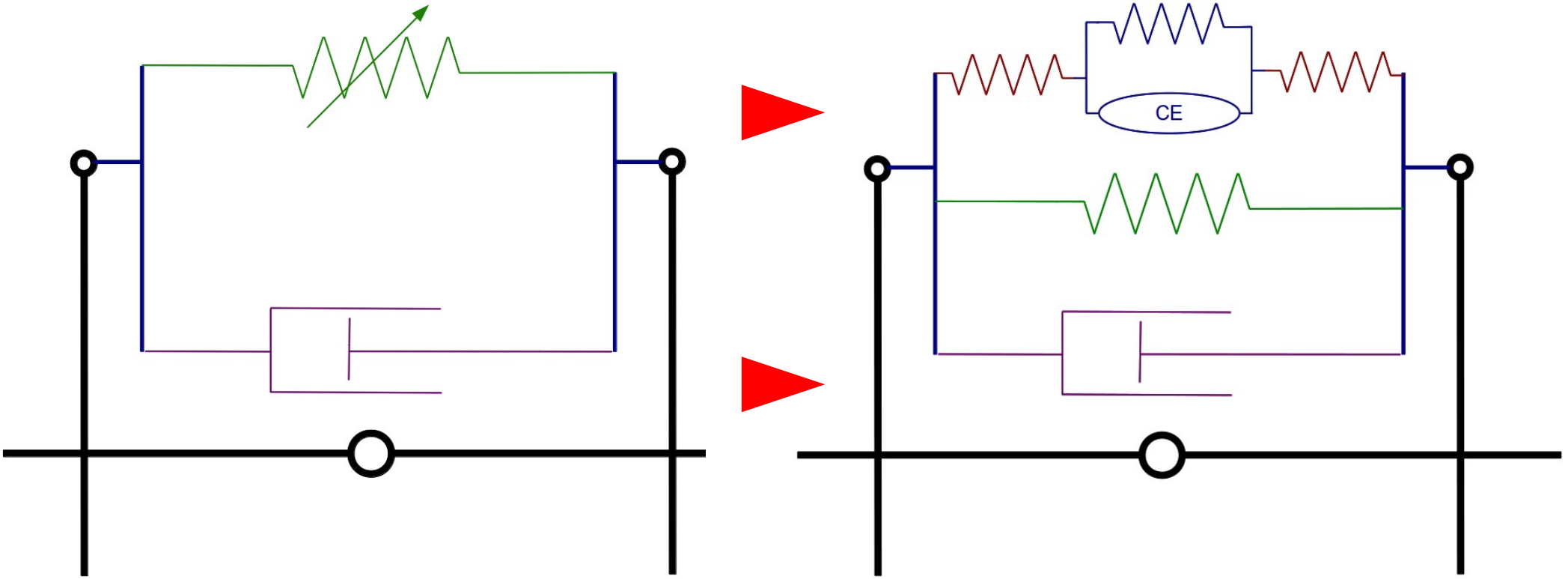


Robotic platform → Reality gap

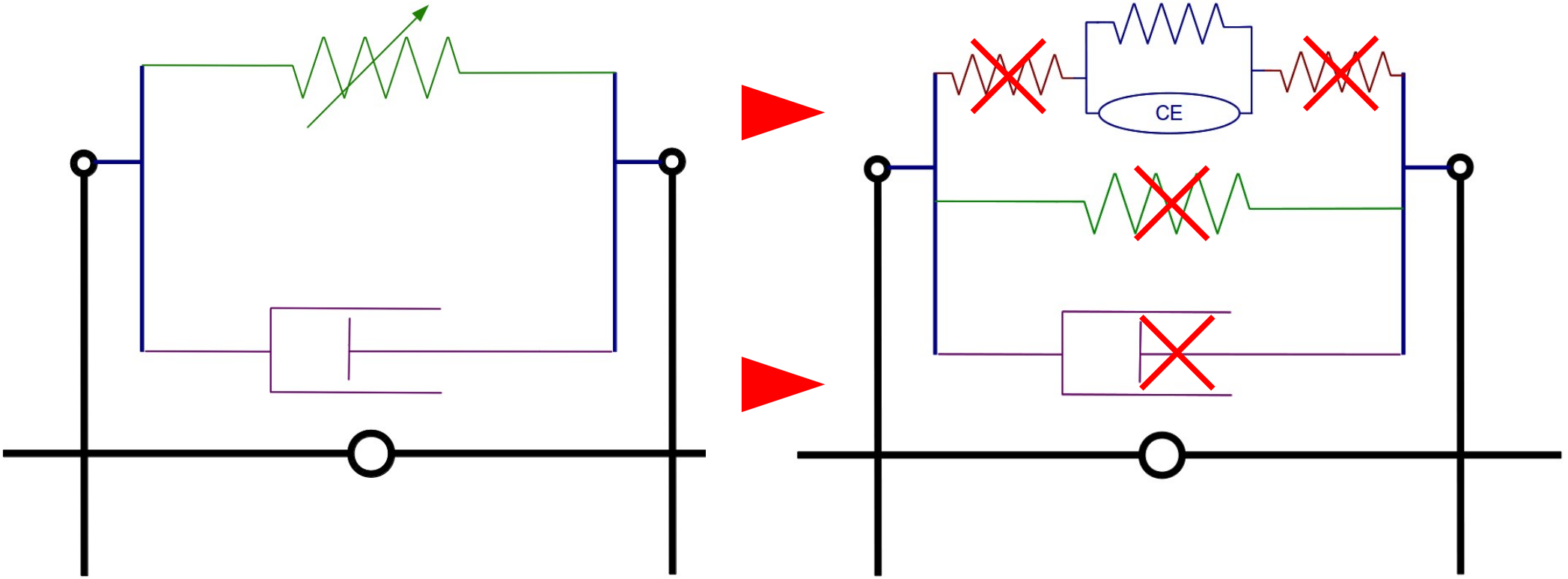
Modeling



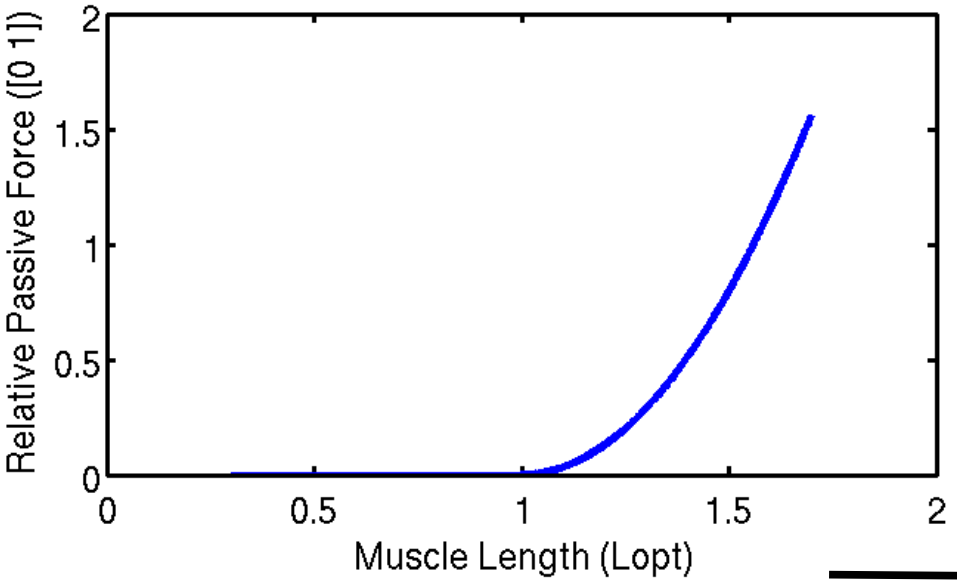
Modeling

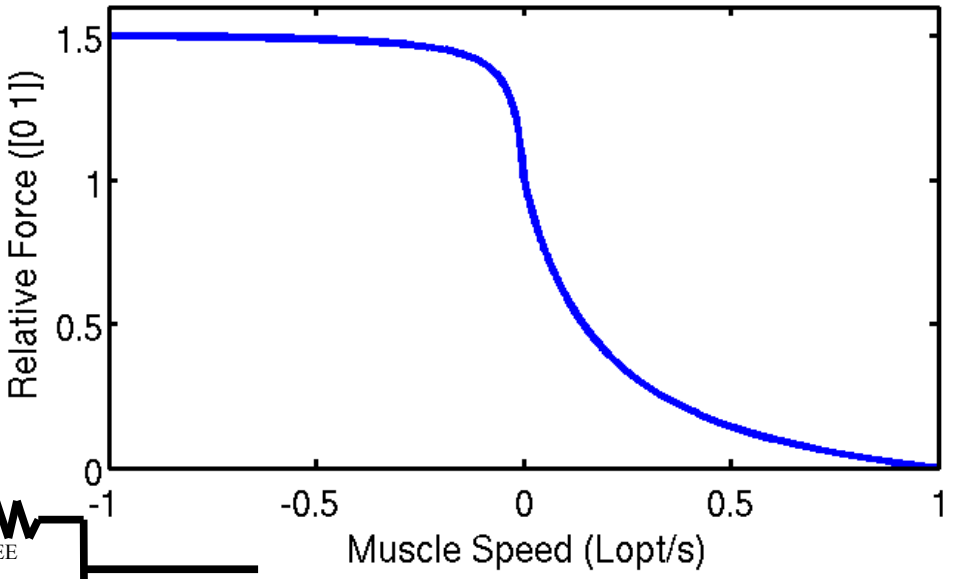


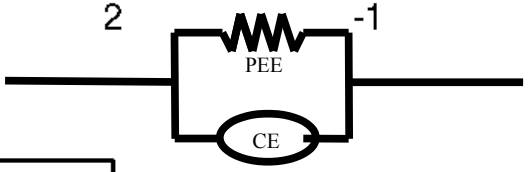
Modeling

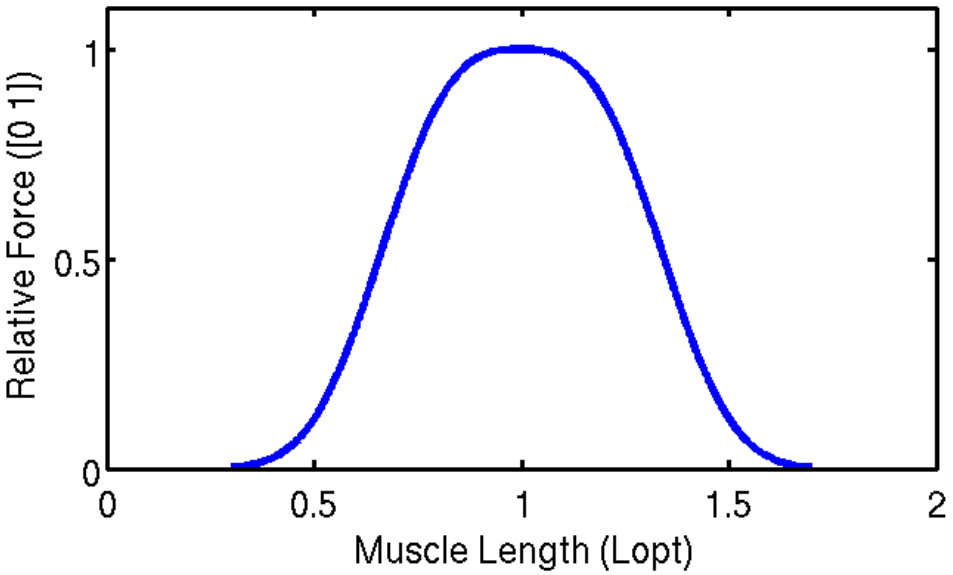


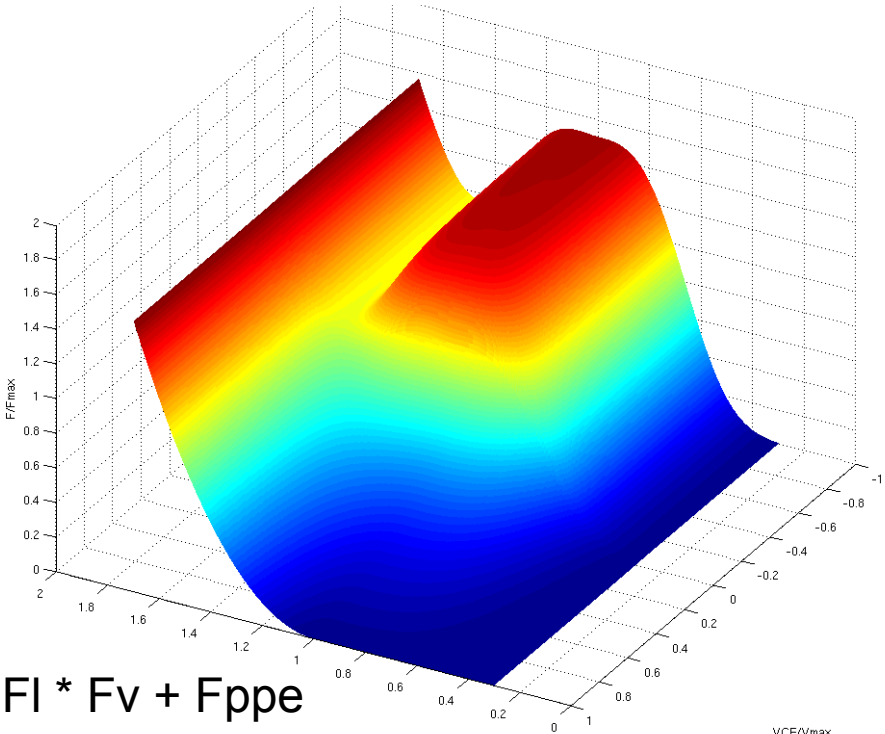
Modeling











Ftot = Fmax * activation * Fl * Fv + Fppe

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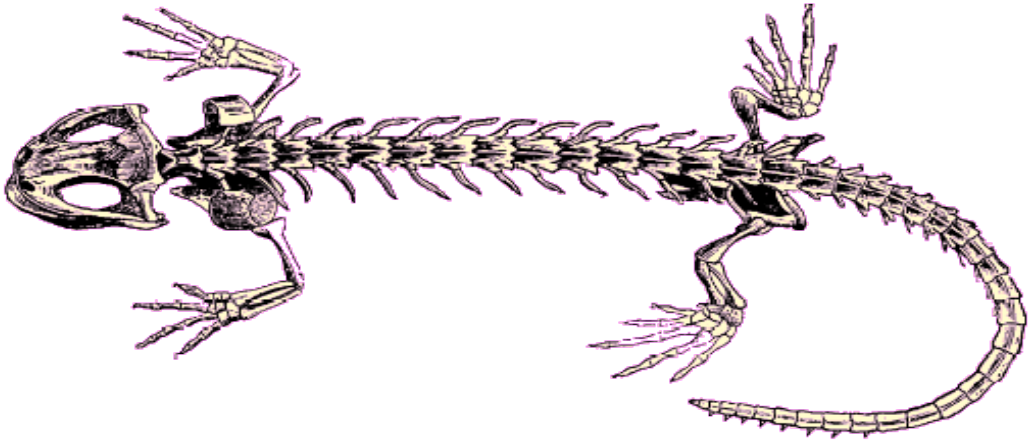
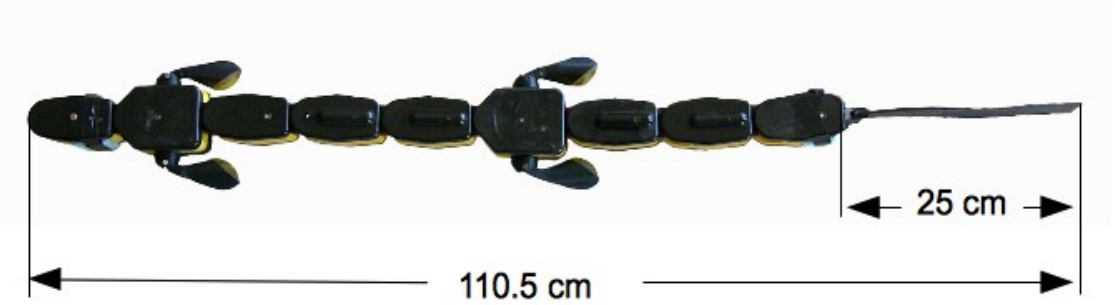
Constraints

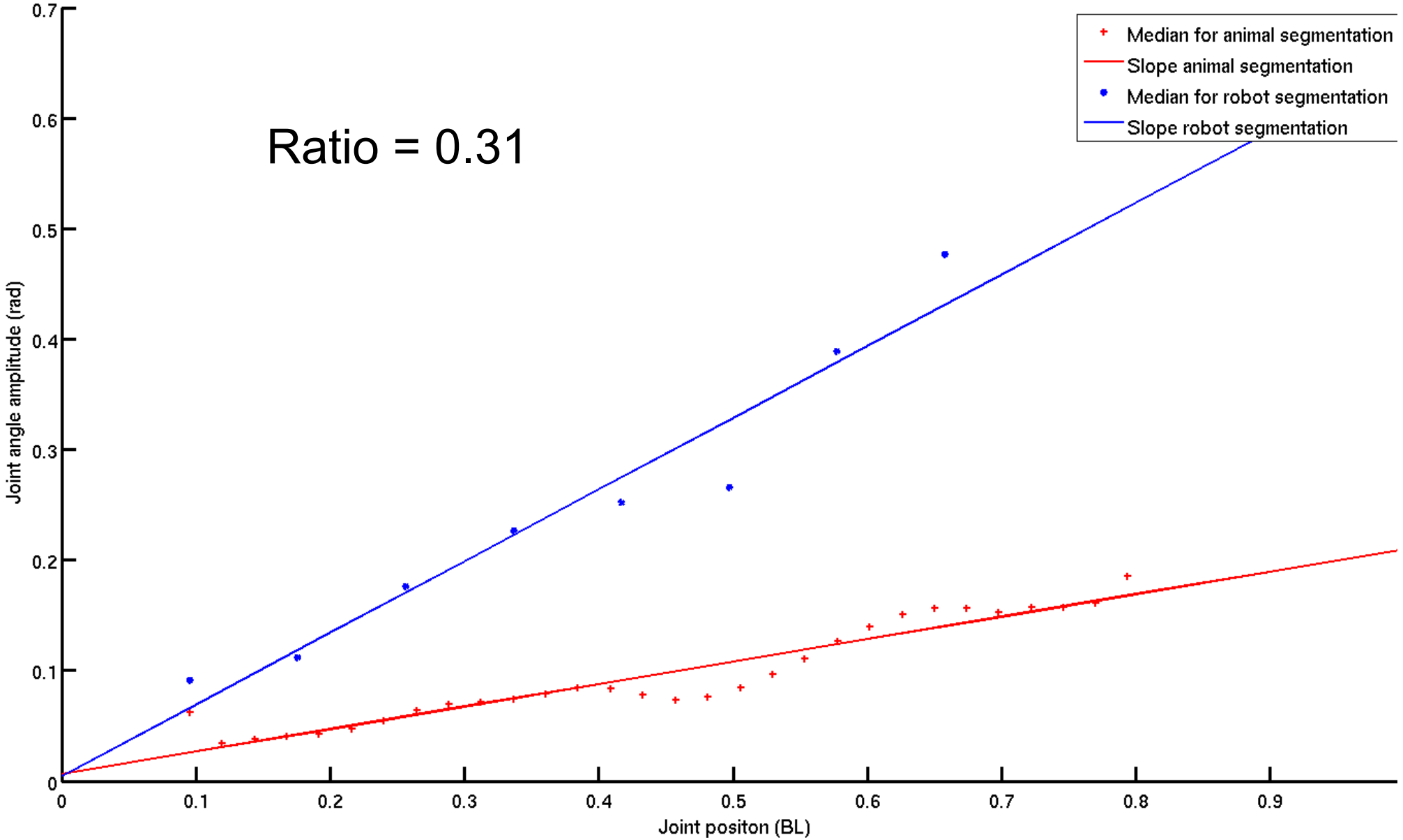


Head
+
40 Segments

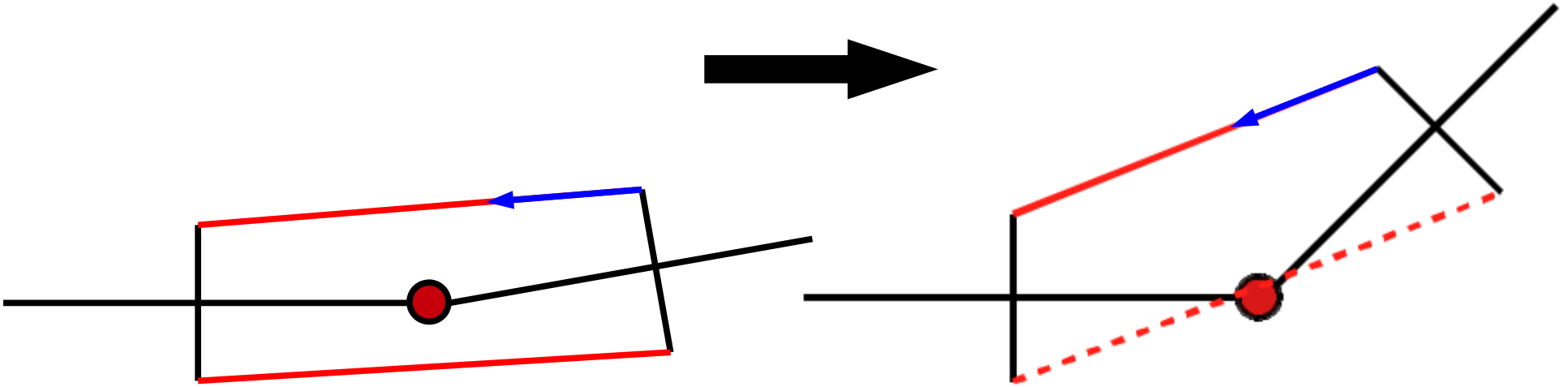


Head
+
8 Segments
+
Tail

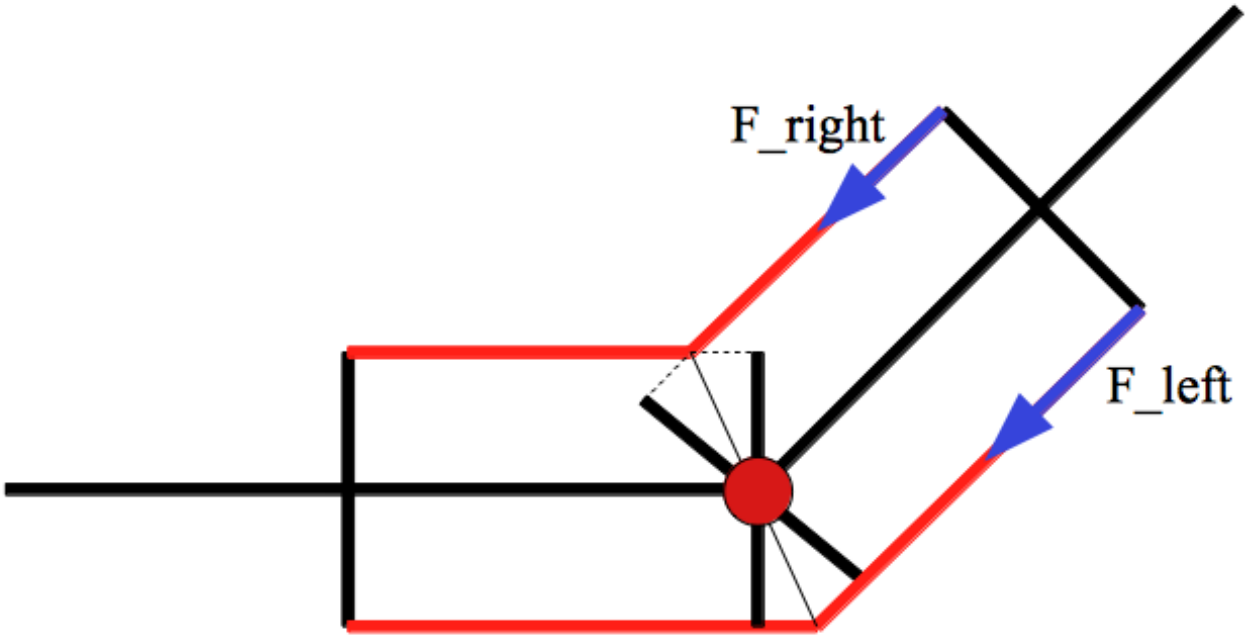
Constraints



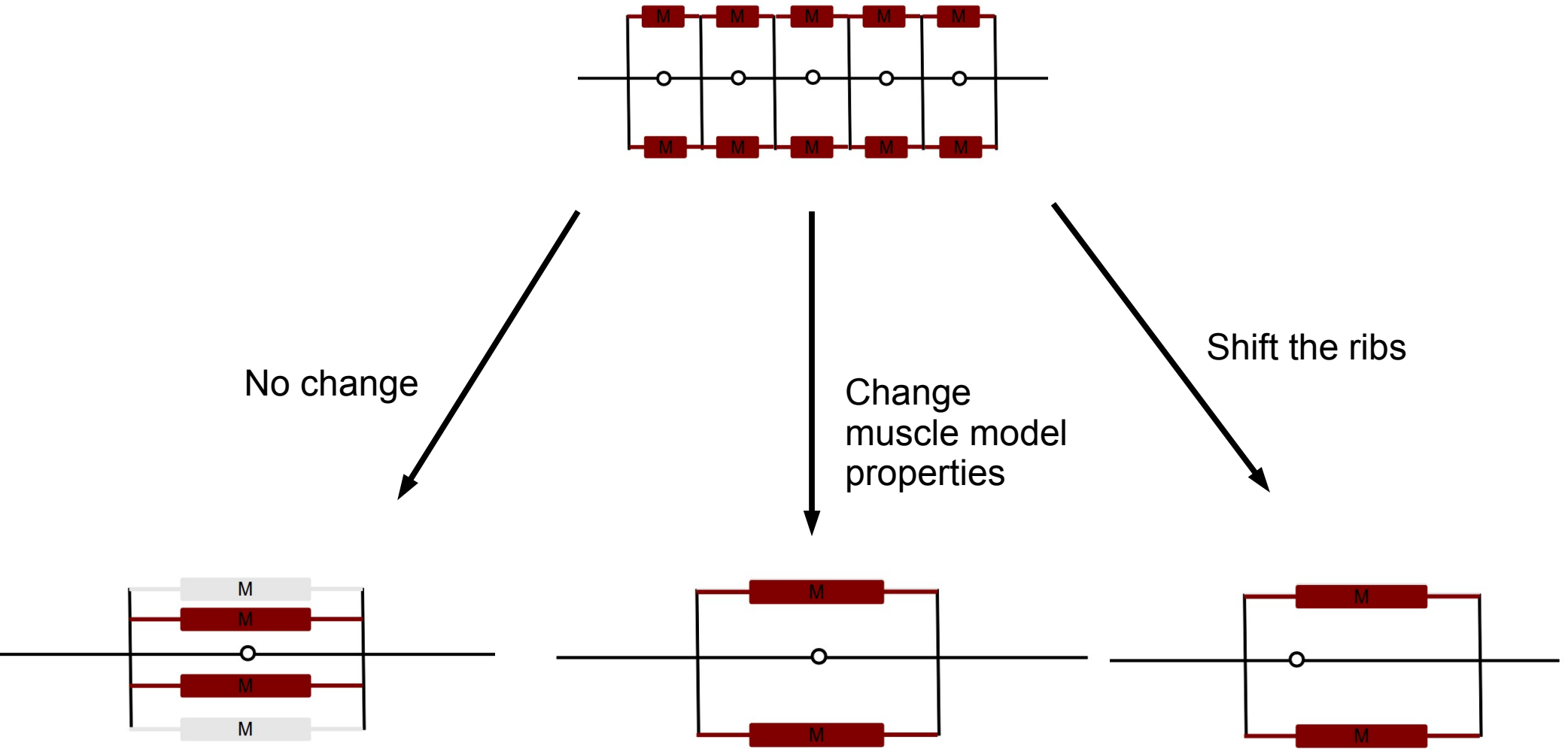
Constraints



Solutions



Solutions


M
M
M
M
M
M
M
M
M
M
No change
Change
muscle model
properties
Shift the ribs
M
M
M
M
M
M
M
M

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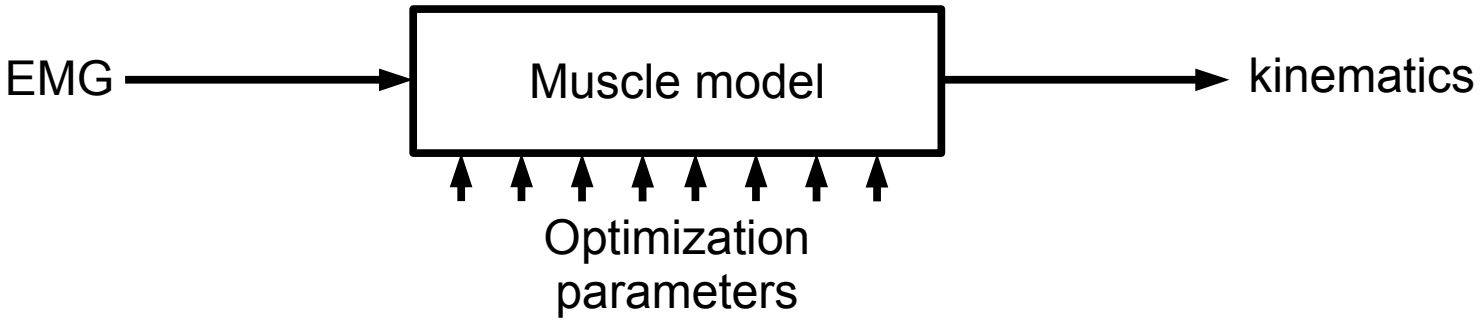
Method

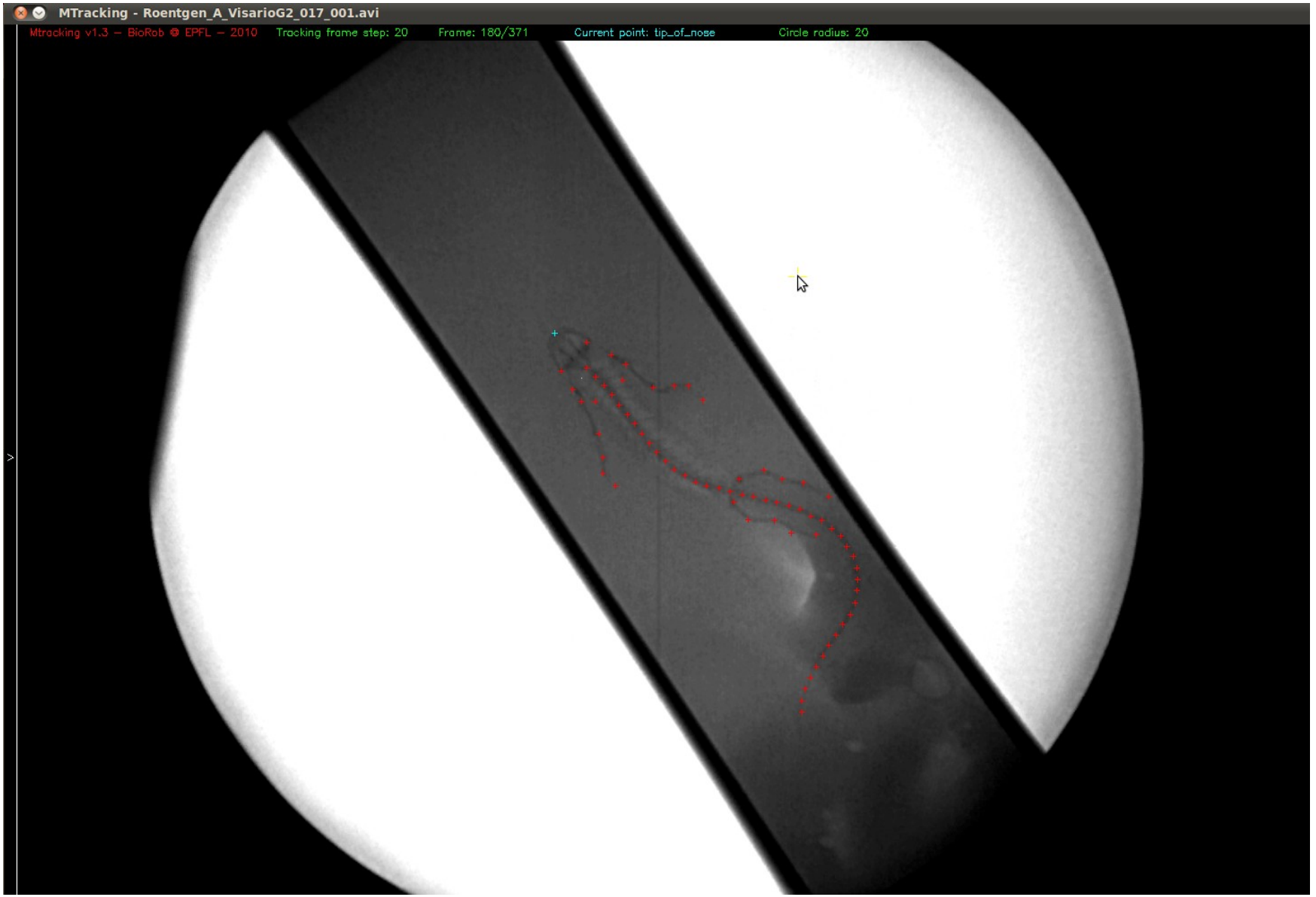


Input : EMG Delvolvé

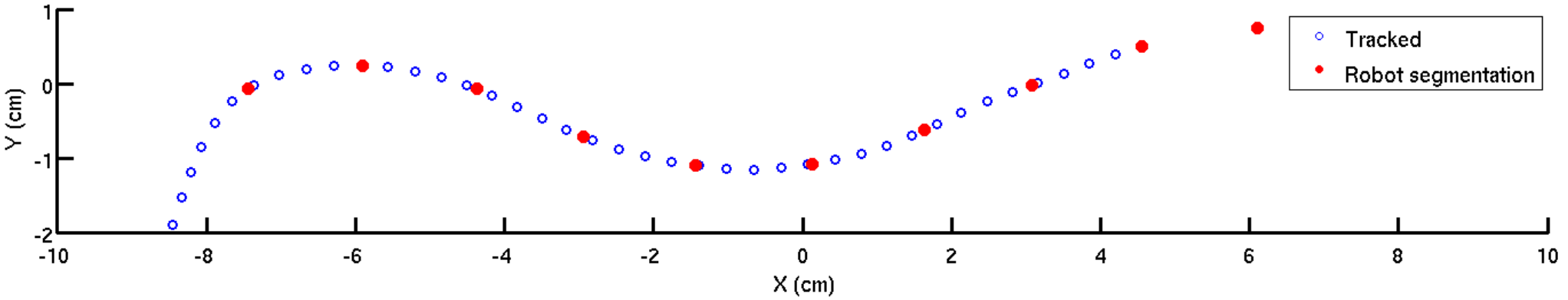
Parameters : Fmax , Lopt , Joint width

Fitness : Match the X-Ray avg kinematics

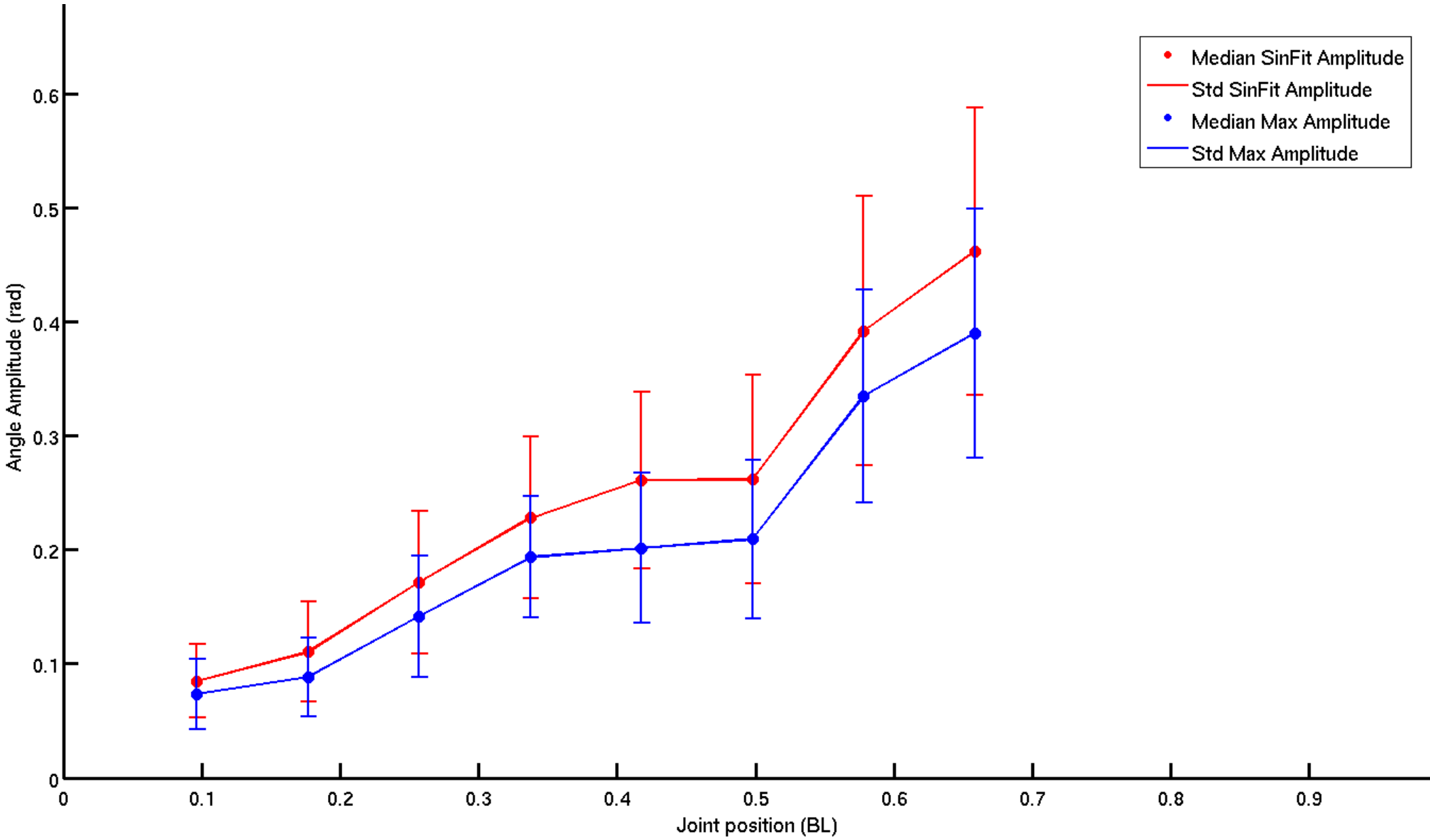
Kinematics


MTracking - Roentgen_A_VisarioG2_017_001.avi
Mtracking v1.3 – BioRob @ EPFL – 2010
Tracking frame step: 20
Frame: 180/371
Current point: tip_of_nose
Circle radius: 20

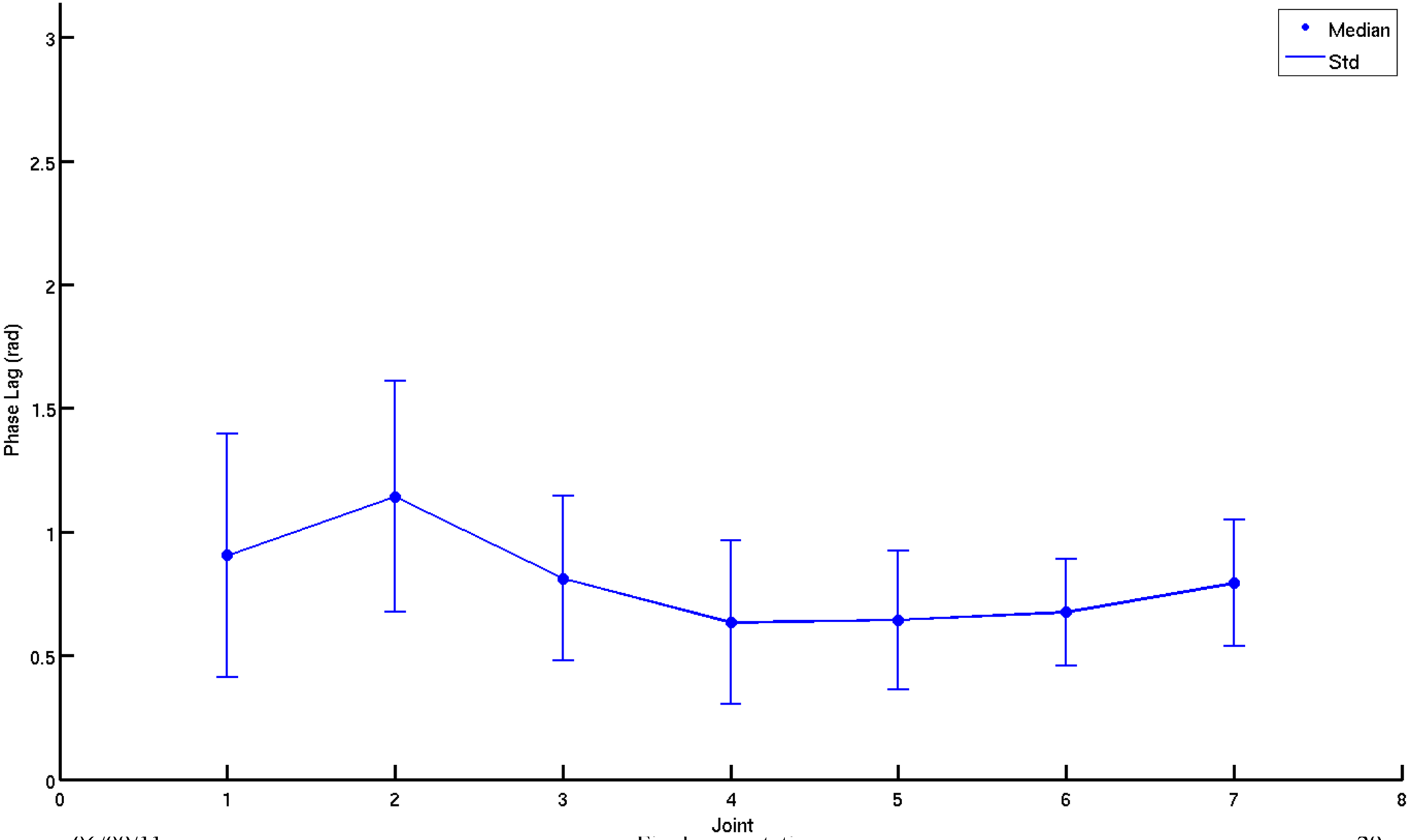
Kinematics



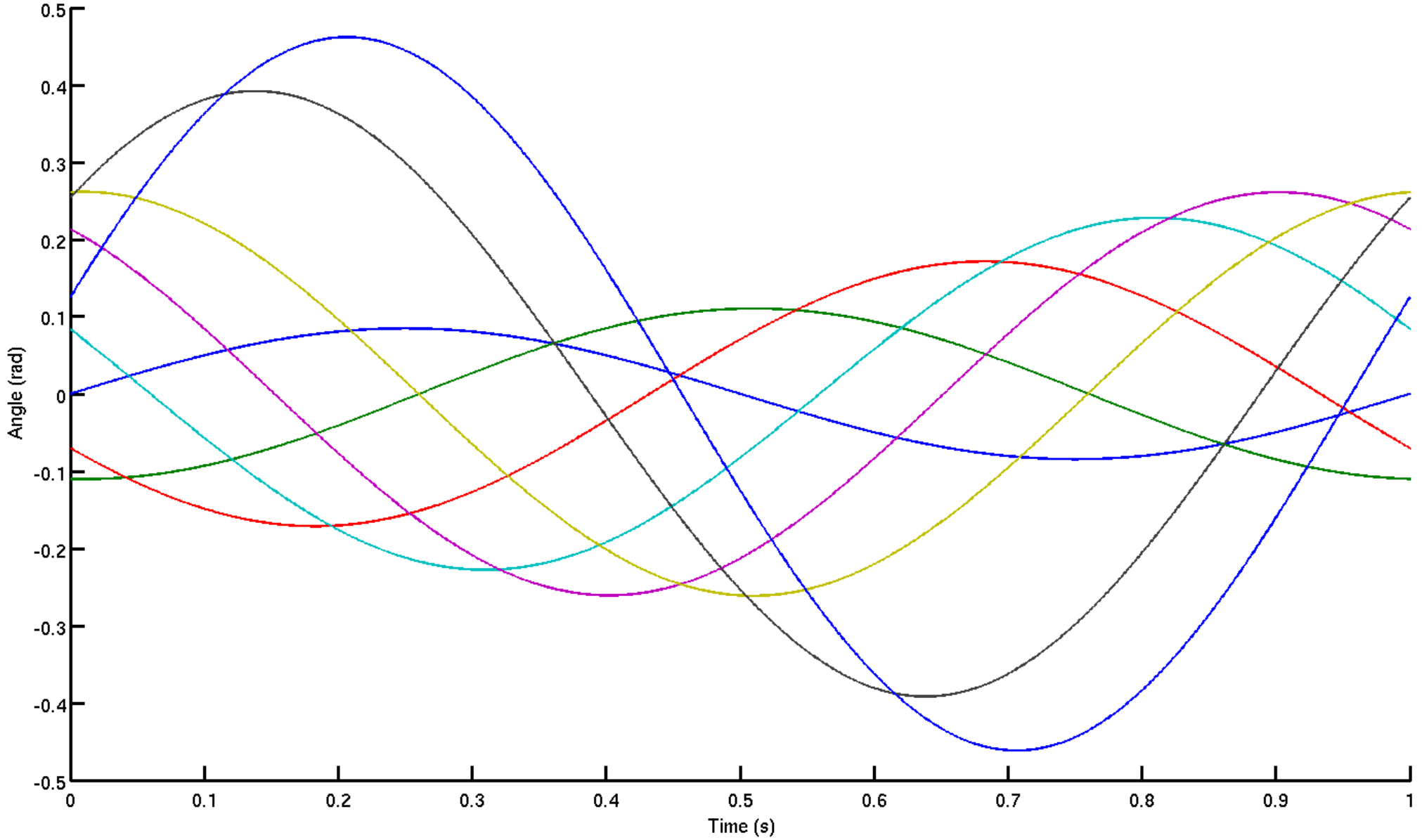
Kinematics

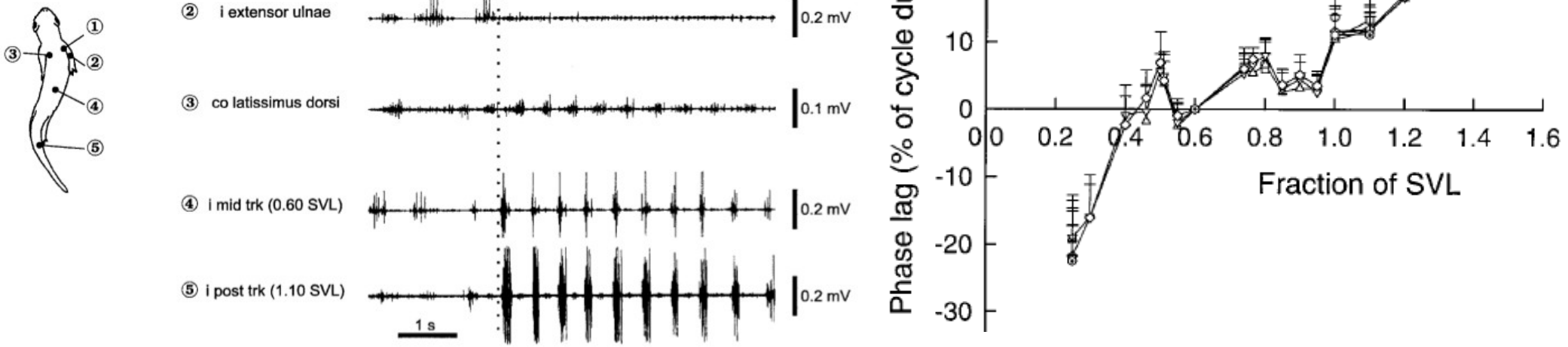

Median SinFit Amplitude
Std SinFit Amplitude
Median Max Amplitude
Std Max Amplitude
Angle Amplitude (rad)
Joint position (BL)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

Kinematics



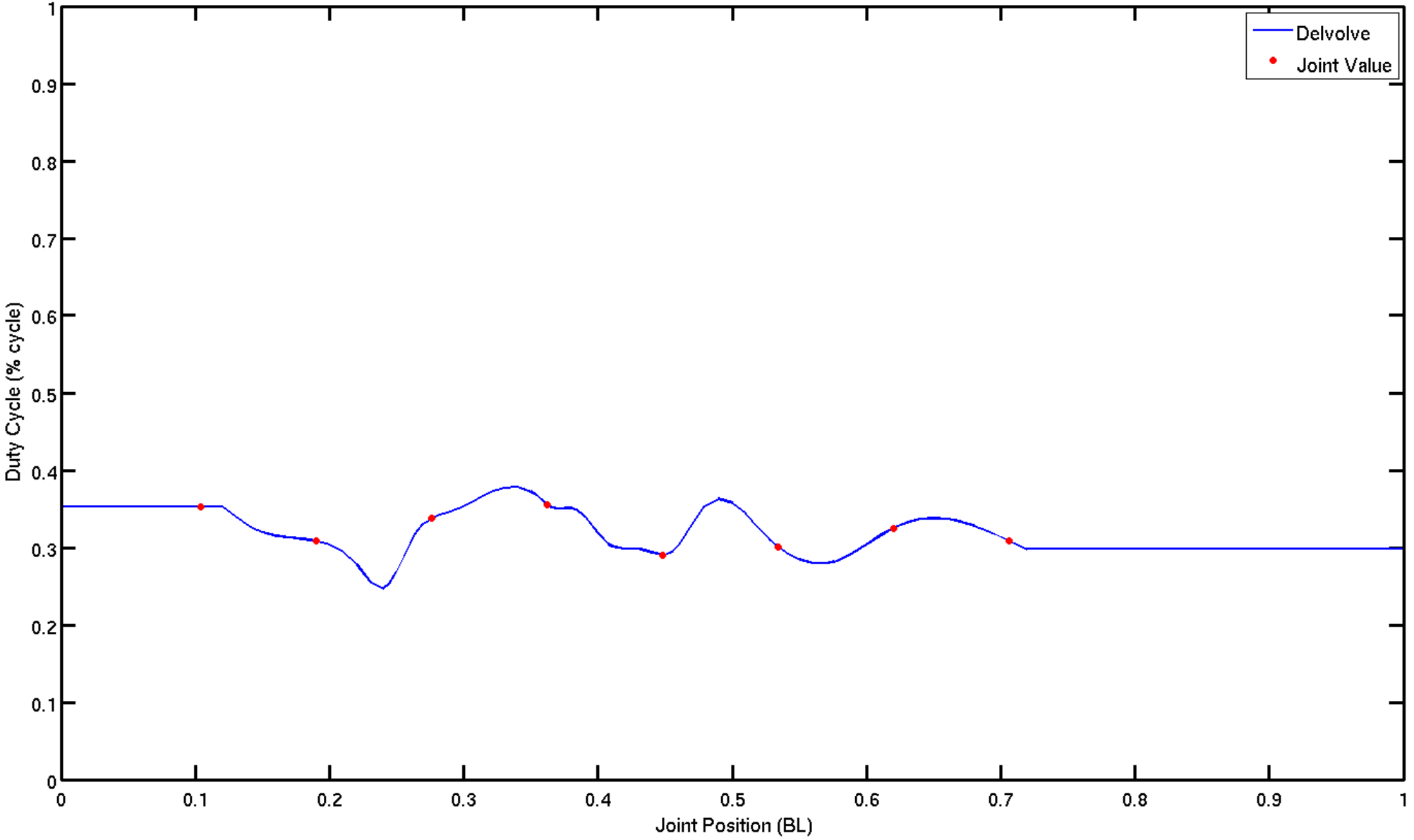
Kinematics


0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
Angle (rad)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Time (s)



Reference :
Epaxial and Limb Muscle Activity During Swimming and Terrestrial Stepping in the Adult Newt
I. DELVOLVE, B. TIAZA, J-M. CABELGUEN 1997

EMG


Delvolve
Joint Value
Duty Cycle (% cycle)
Joint Position (BL)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

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EMG

BIOROB
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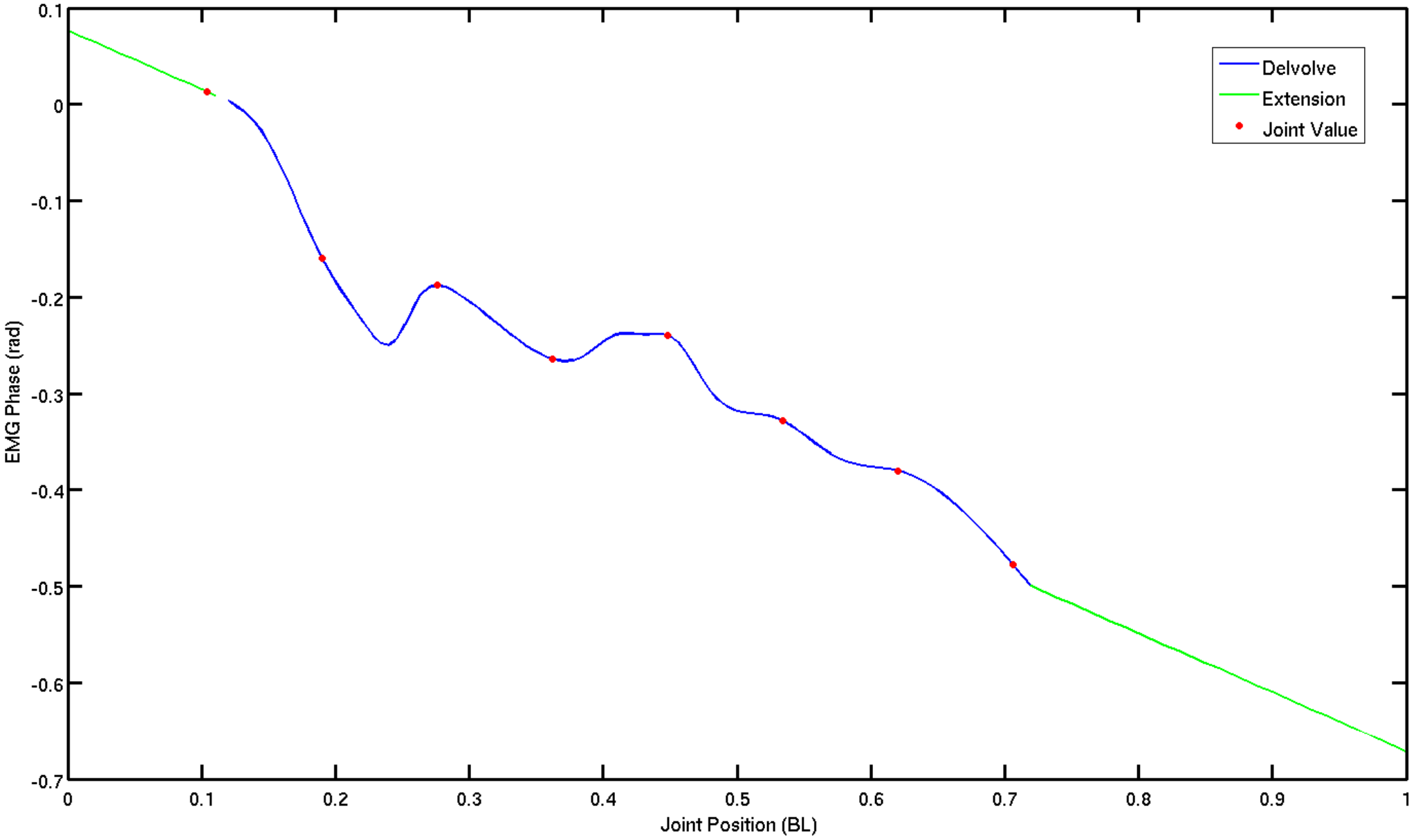
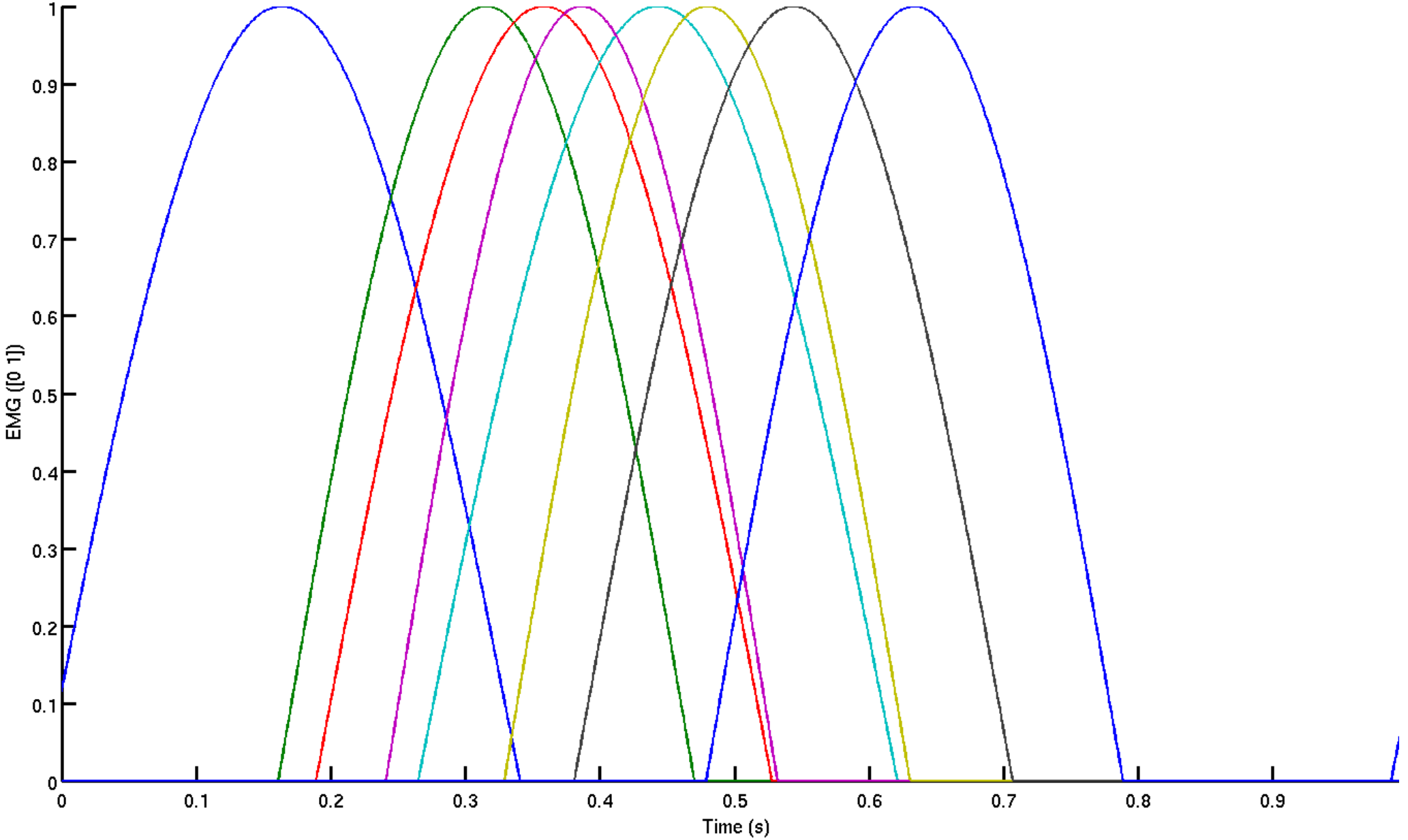
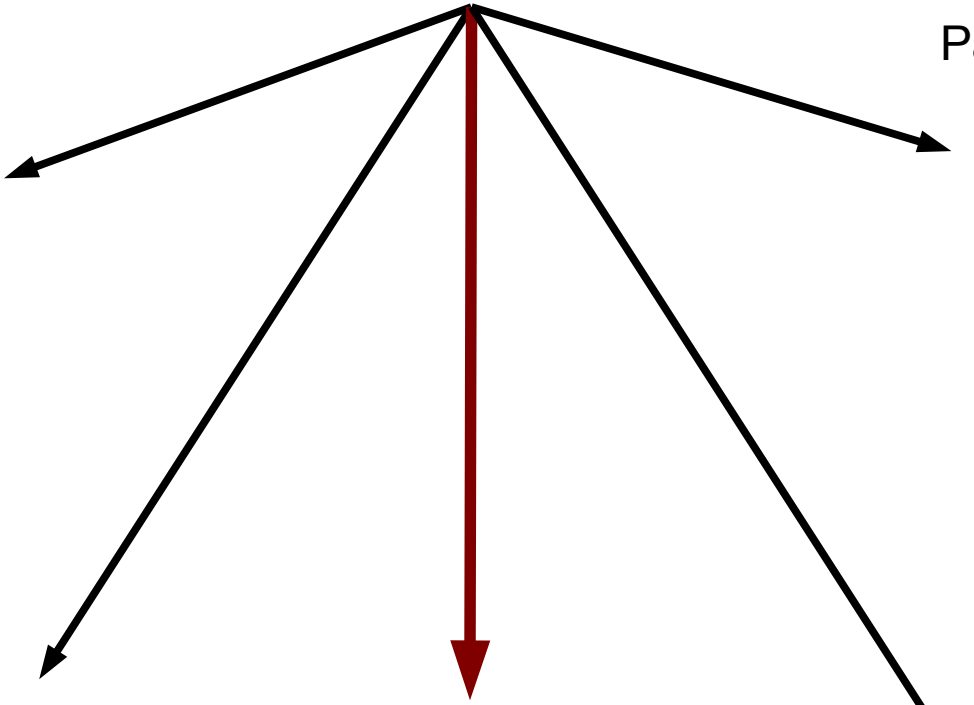


EMG



Setup

Parameters : Fmax , Lopt , Joint width



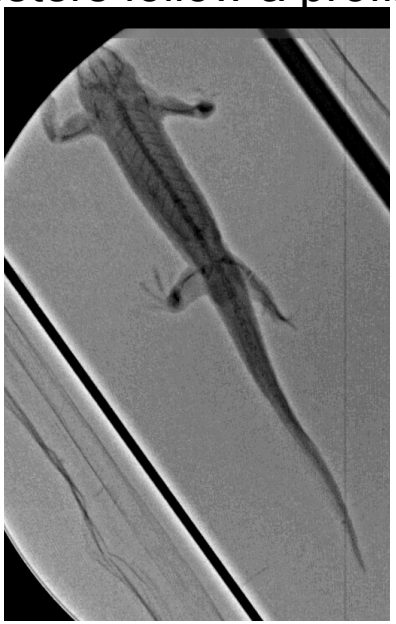
Same for all joints

All parameters free
No boundary

All parameters free
Boundary

All parameters free
Restricted boundary

Parameters follow a profile



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Results

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Results

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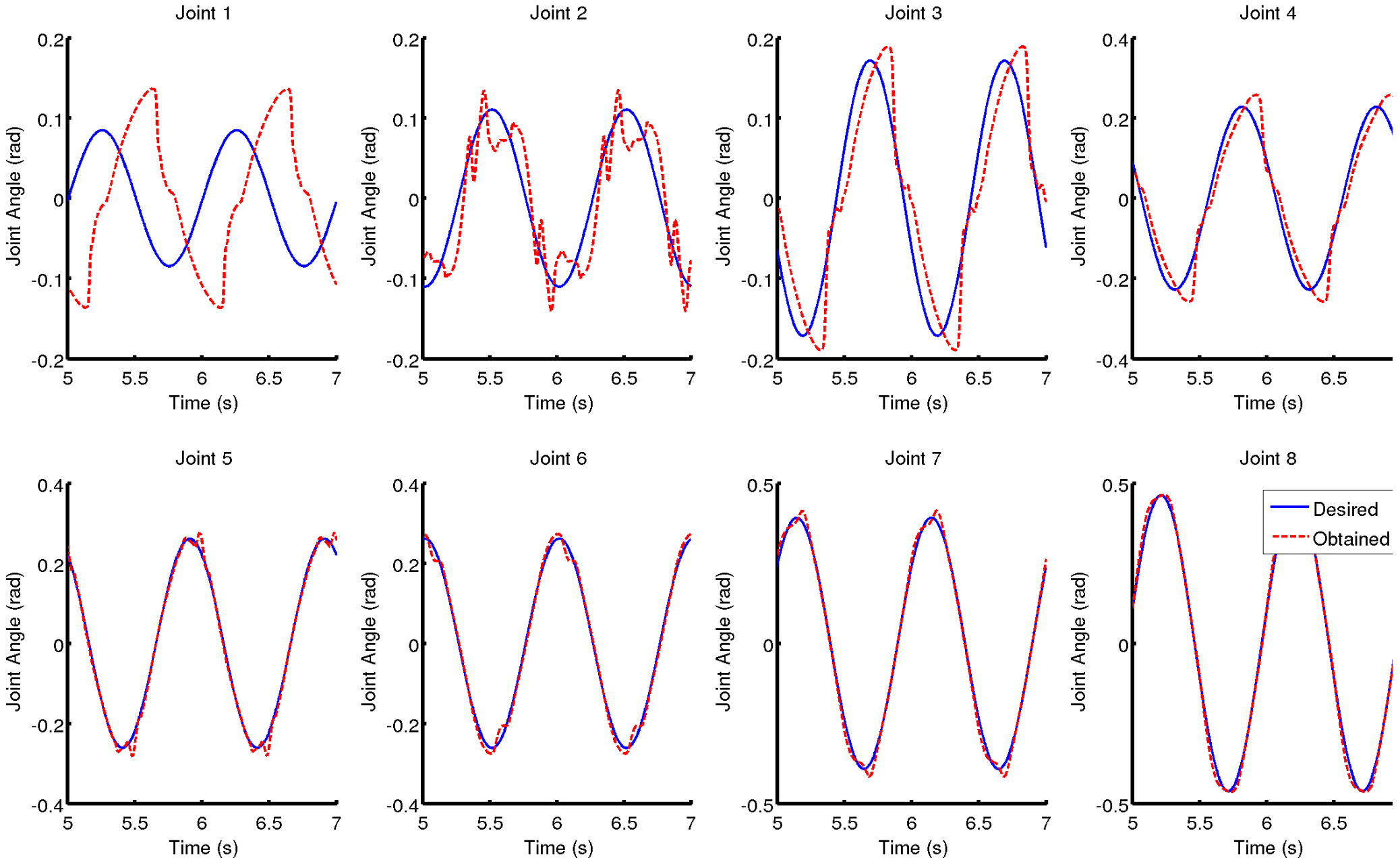
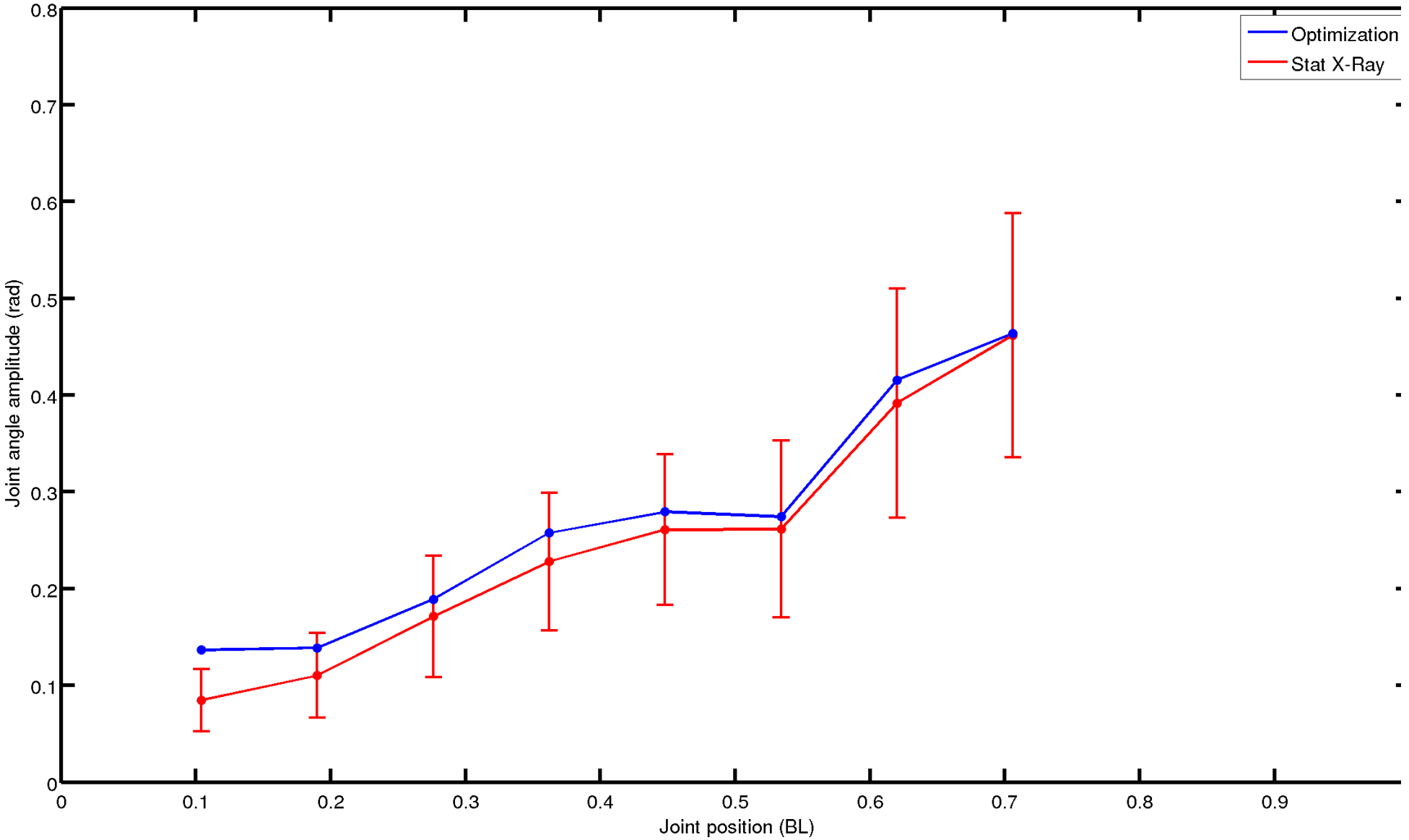
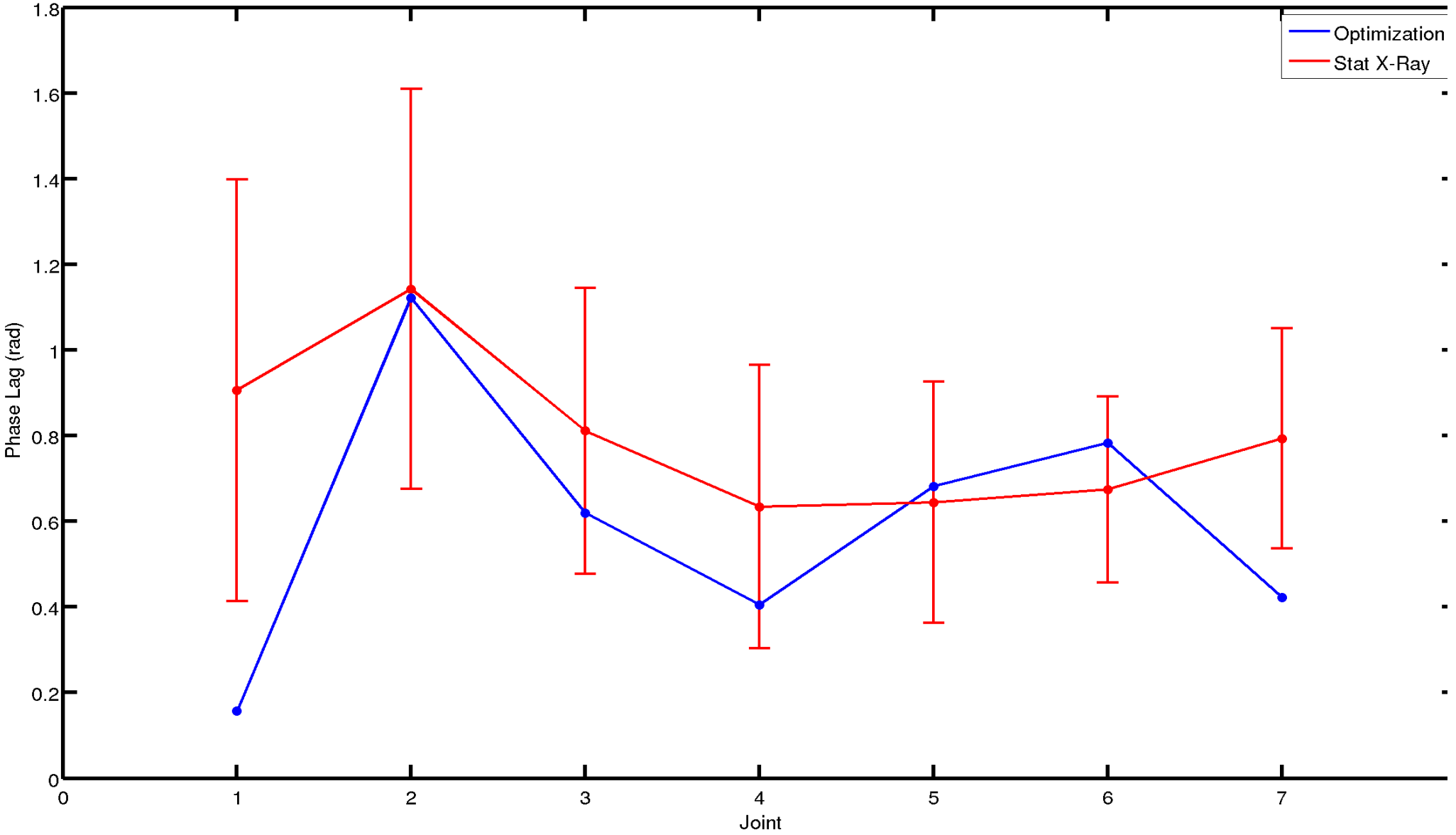


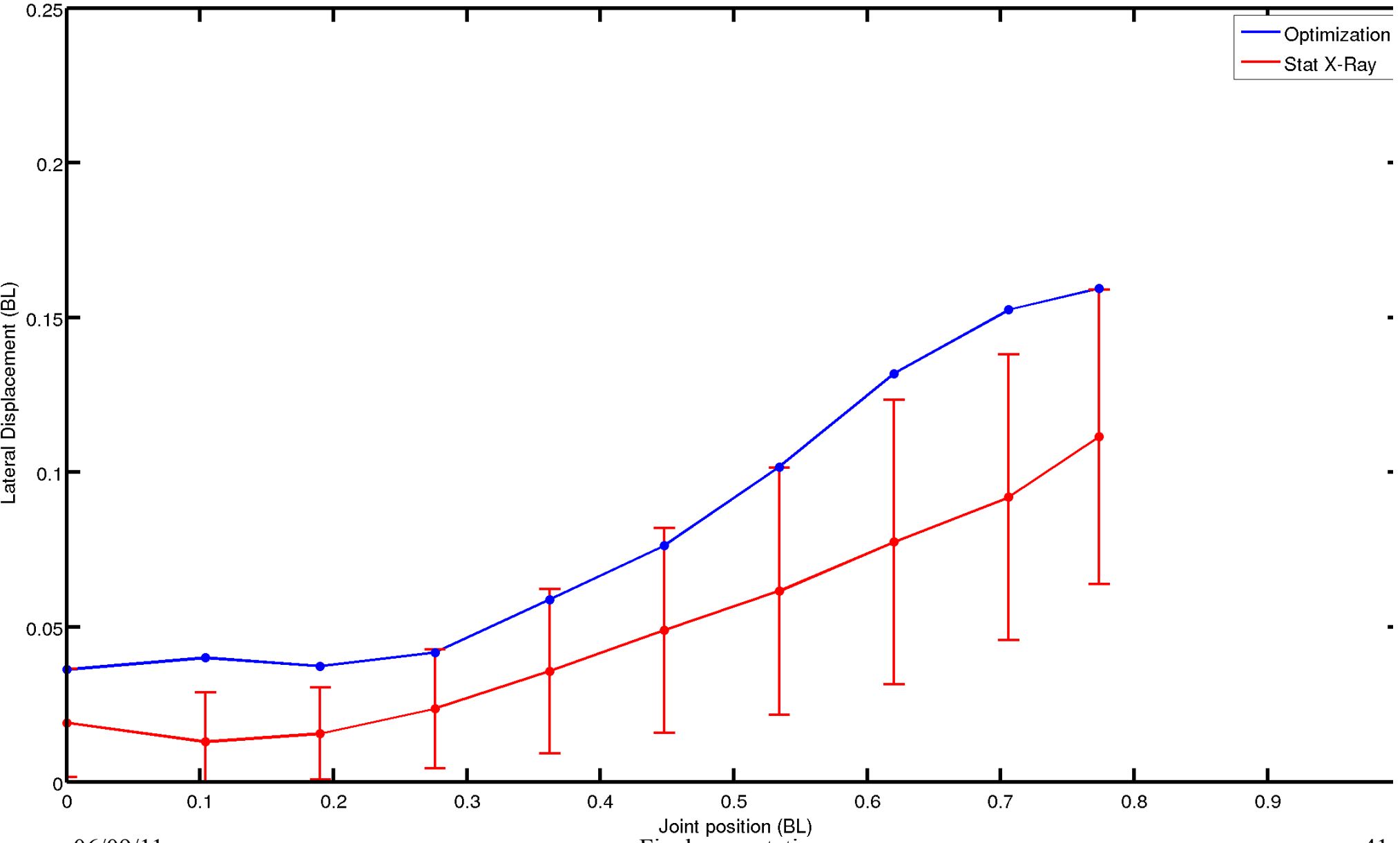
Results


Optimization
Stat X-Ray
Joint angle amplitude (rad)
Joint position (BL)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

Results

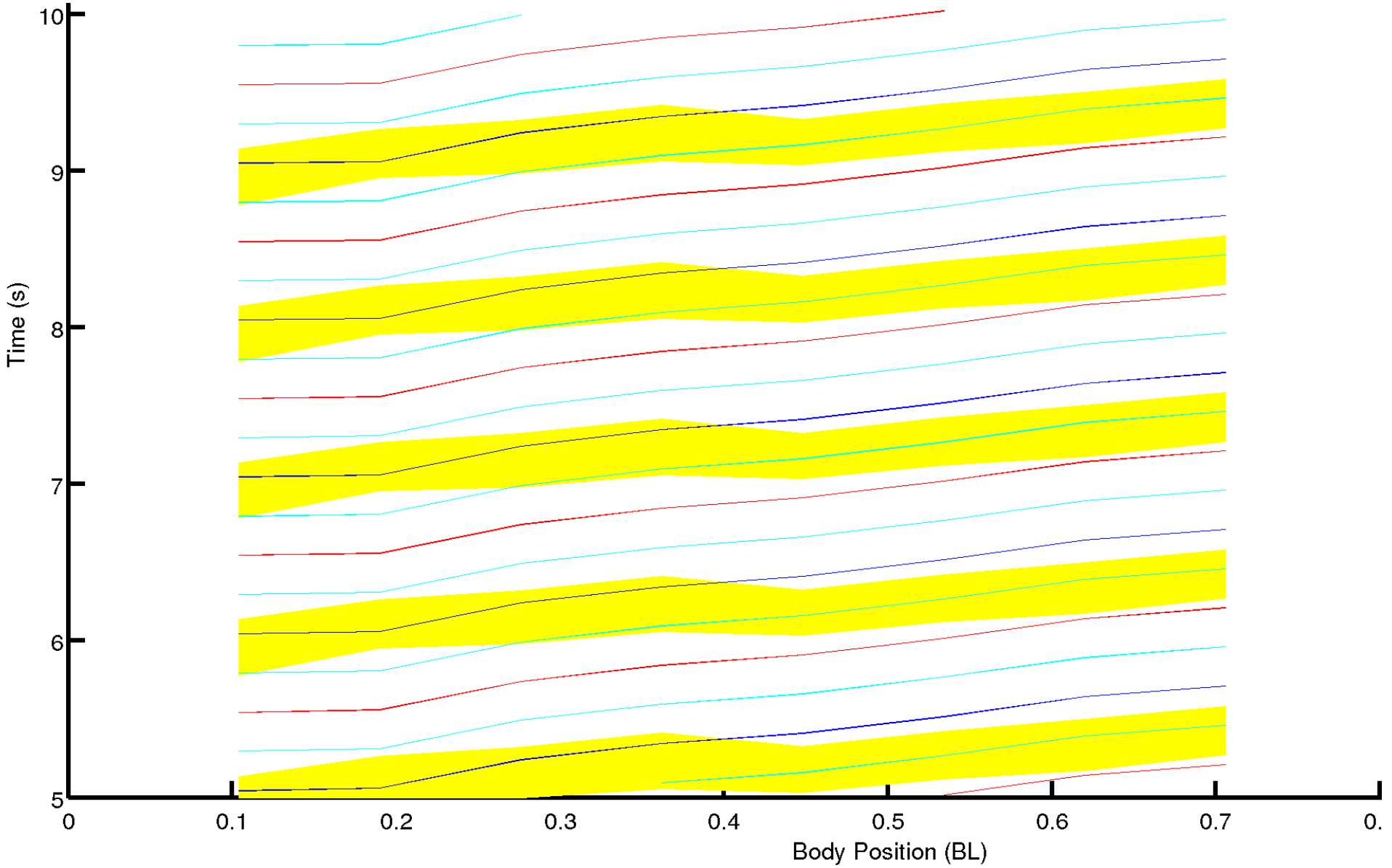

Optimization
Stat X-Ray
Phase Lag (rad)
Joint
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
0
1
2
3
4
5
6
7

Results

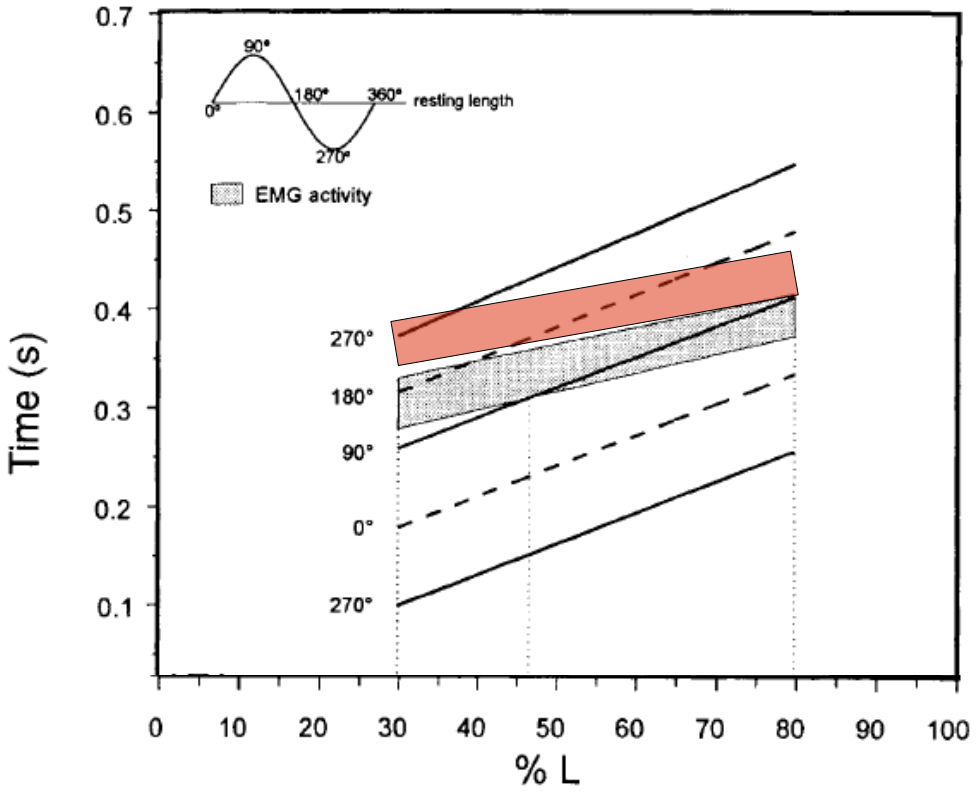

Optimization
Stat X-Ray
Lateral Displacement (BL)
Joint position (BL)
0.25
0.2
0.15
0.1
0.05
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

Results

Results

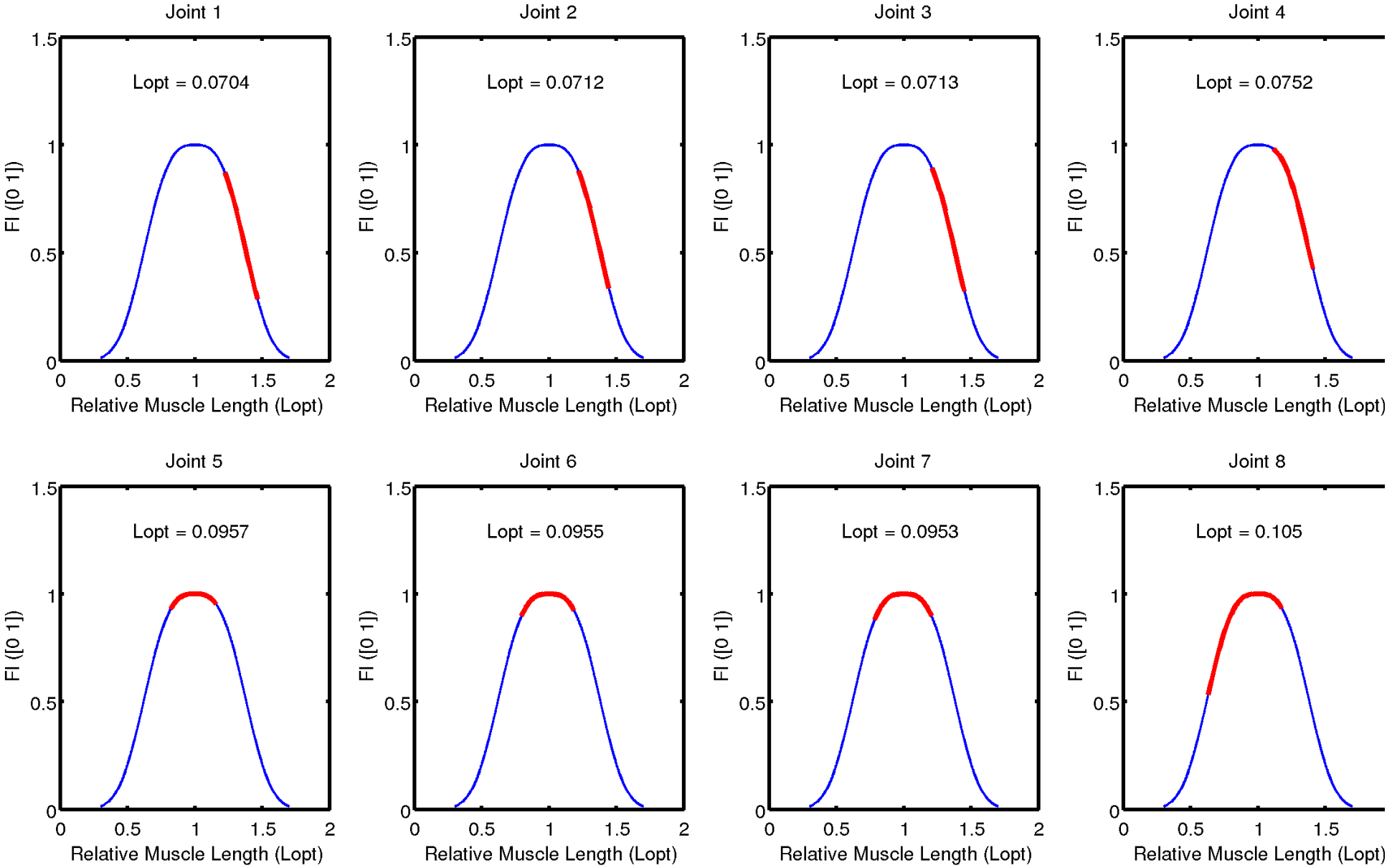


Results



Reference :
The Timing of Muscle Strain And Activation During Steady Swimming in a salamander
K. D'AOUT et al.

Results


Joint 1
Lopt = 0.0704
Joint 2
Lopt = 0.0712
Joint 3
Lopt = 0.0713
Joint 4
Lopt = 0.0752
Joint 5
Lopt = 0.0957
Joint 6
Lopt = 0.0955
Joint 7
Lopt = 0.0953
Joint 8
Lopt = 0.105
Fl ([0 1])
Relative Muscle Length (Lopt)

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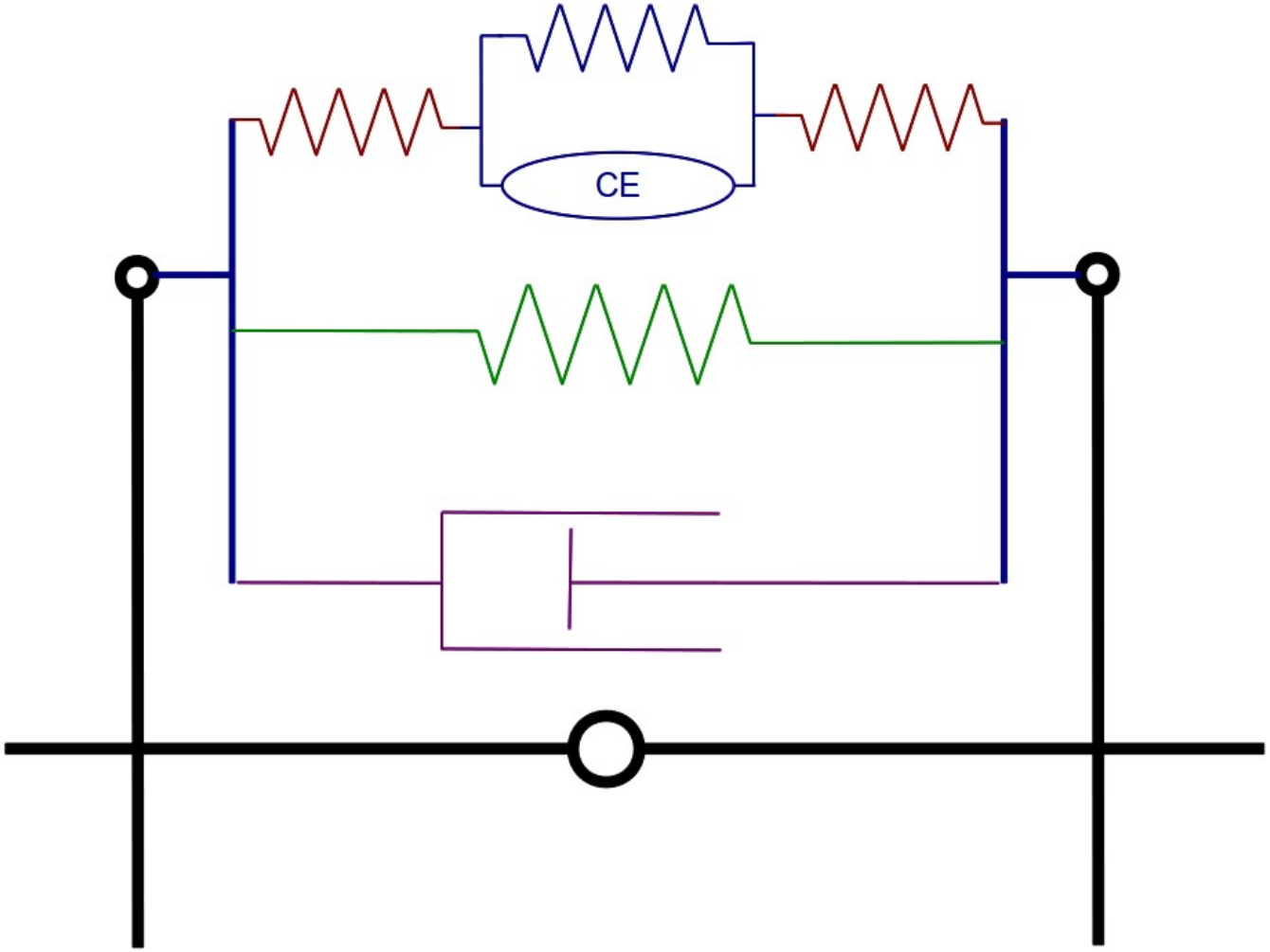
Improvements



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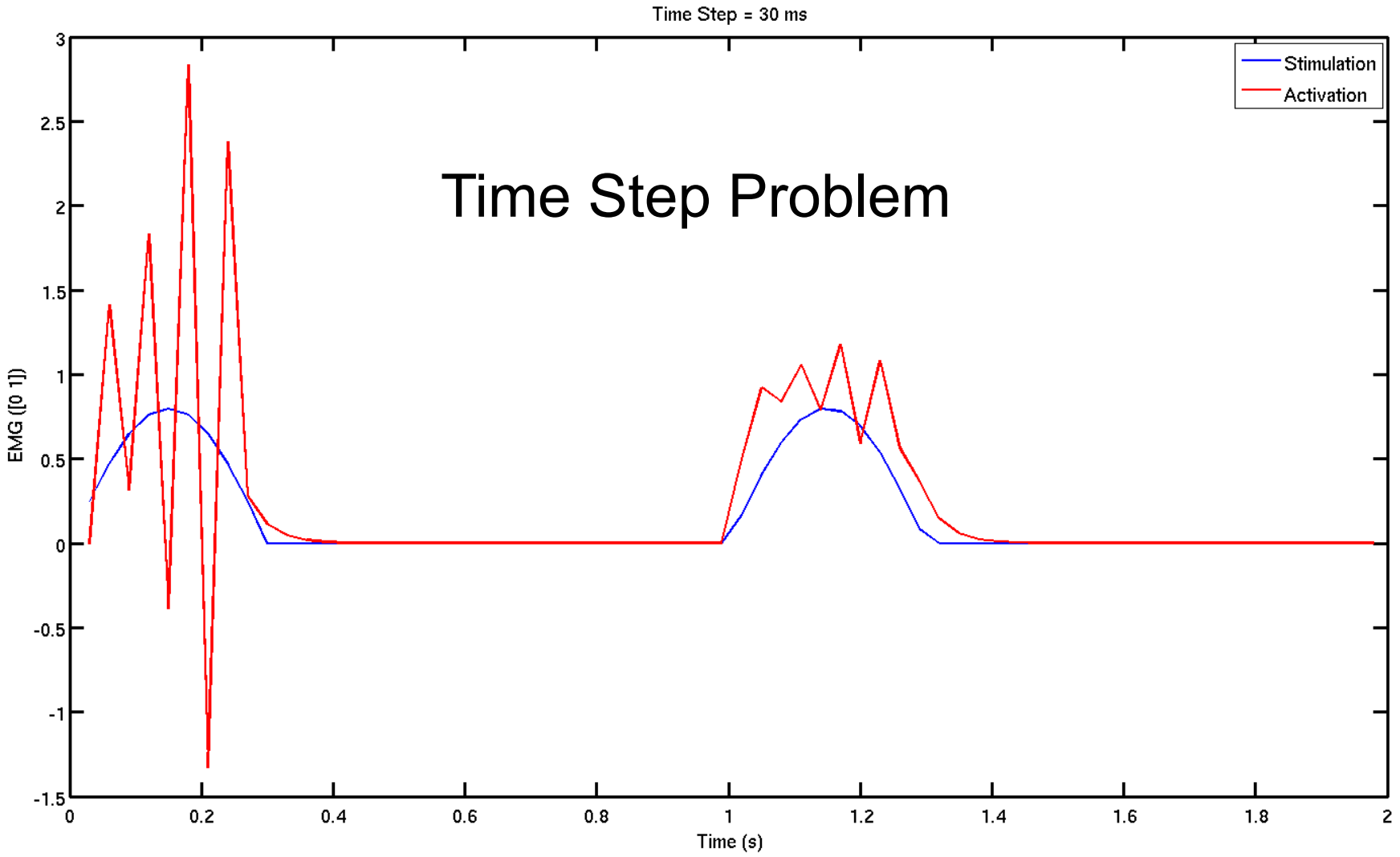
- Future Works

Problem



/Users/jgrizou/Desktop/Final_presentation/images/Robot_test/Crazy_oscillation.m4v

Solutions

Decrease the time step :

- Initial → 40 ms

- Delete CPG + unnecessary request → 15 ms

- Communication without acknowledge → 11 ms

- Broadcast protocol → 5-7 ms

Results

/jgrizou/Desktop/Final_presentation/images/Robot_test/Salamander_passive_vertical.m4v

/jgrizou/Desktop/Final_presentation/images/Robot_test/Short_good_swim_low_freq.m4v

ers/jgrizou/Desktop/Final_presentation/images/Robot_test/Slamander_lowfreq_turn.m4v

Future Works

Tendons + Spring

EMG with coupled oscillators + feedback

Computation in each robotic segment

Thank you for your time

Any questions?