ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

BIOROB
EPFL Biorobotics Laboratory

Musculoskeletal modeling of the swimming salamander

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10/06/11

Motivations

Understanding the role of muscles during swimming

Use the robots as an animal model to investigate hypotheses

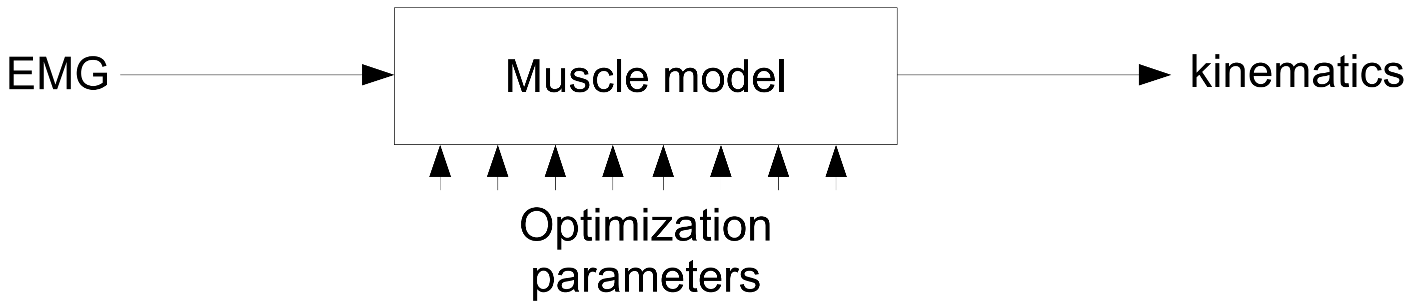
Use biology to design more efficient robot

Objectives

- extract kinematics data from X-ray movies

- muscle/joint model + metabolic cost estimation

- muscle optimization using EMG & kinematics

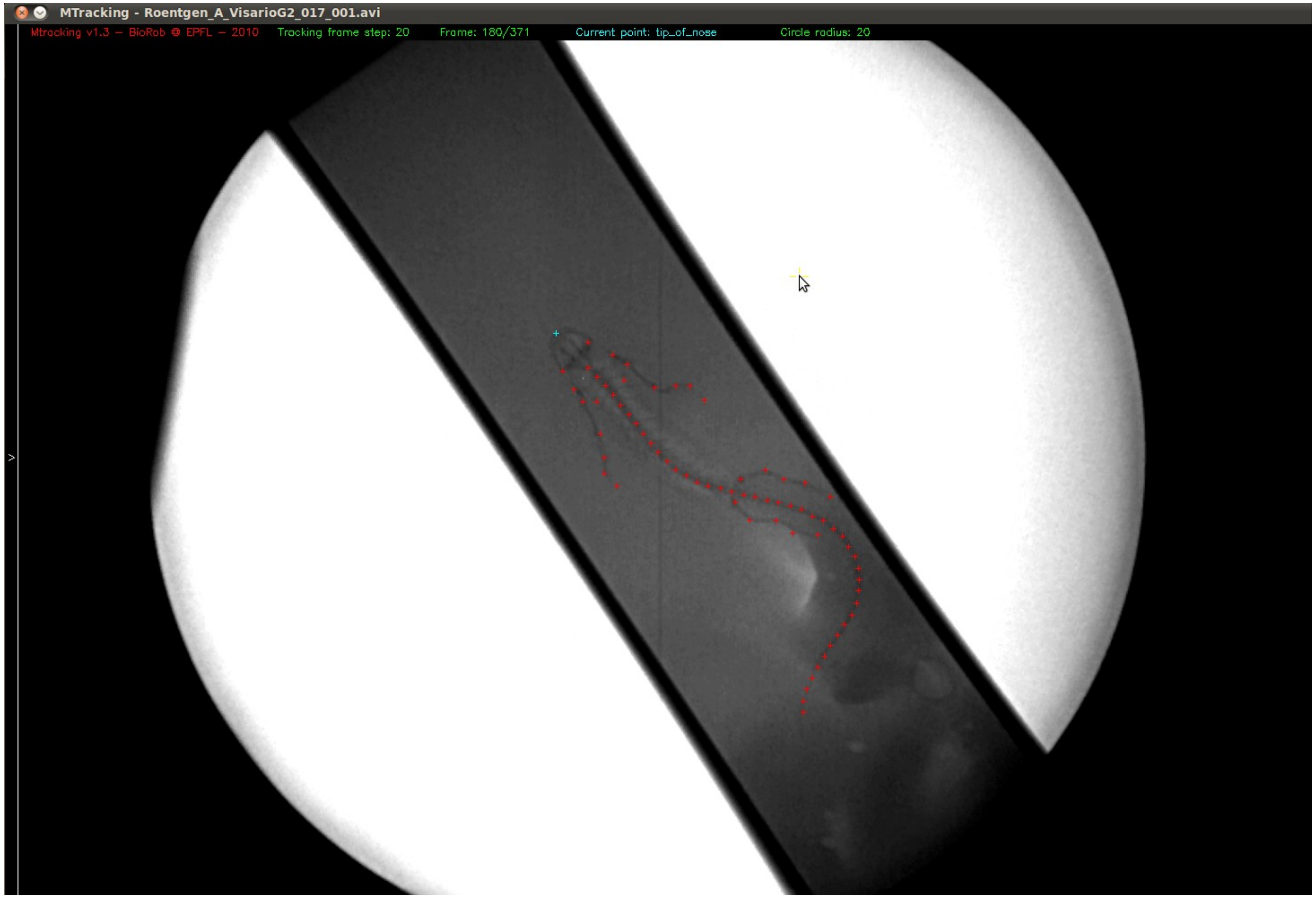


- from simulation to robot

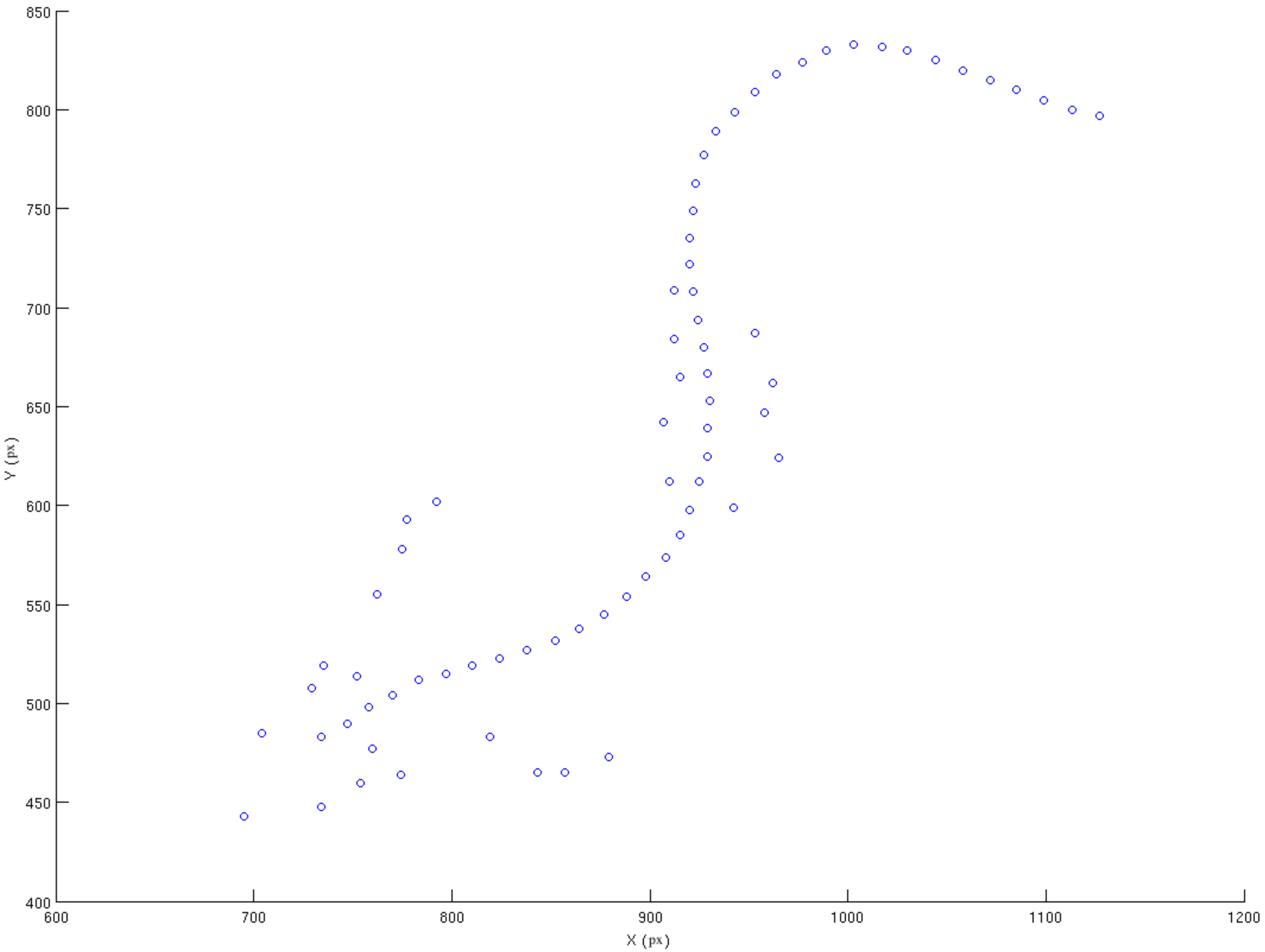
- investigations

X-ray

X-ray

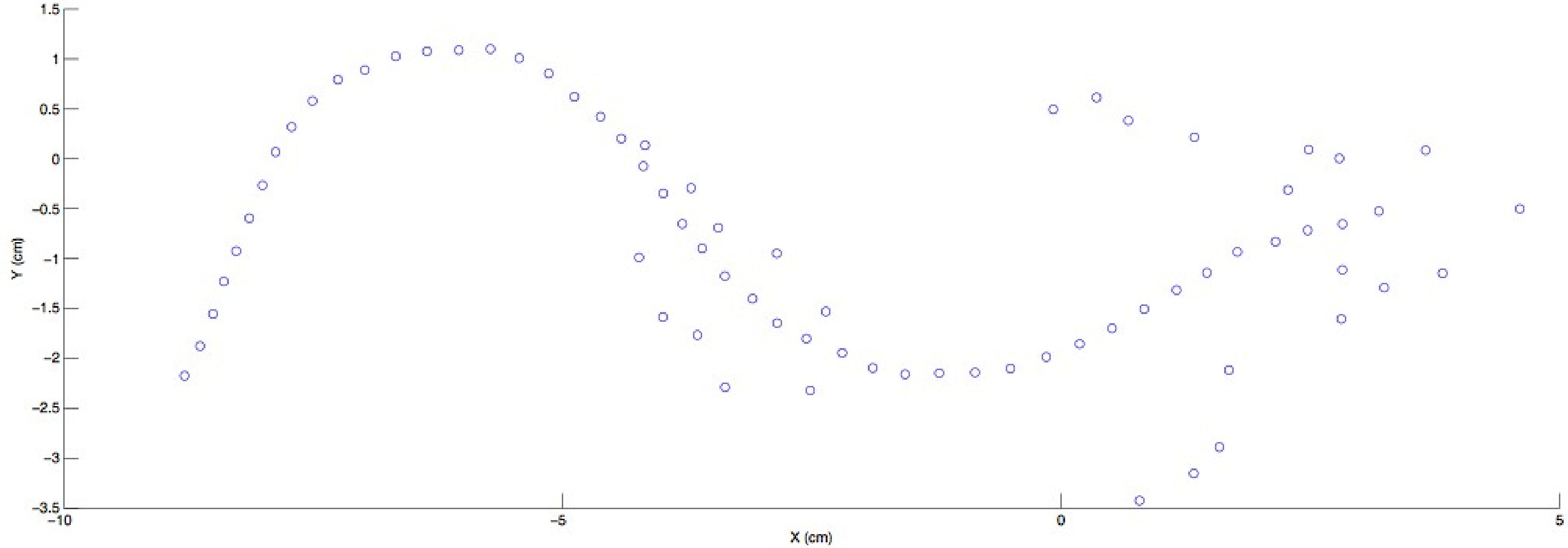

MTracking - Roentgen_A_VisarioG2_017_001.avi
Mtracking v1.3 – BioRob © EPFL – 2010
Tracking frame step: 20
Frame: 180/371
Current point: tip_of_nose
Circle radius: 20

Kinematics

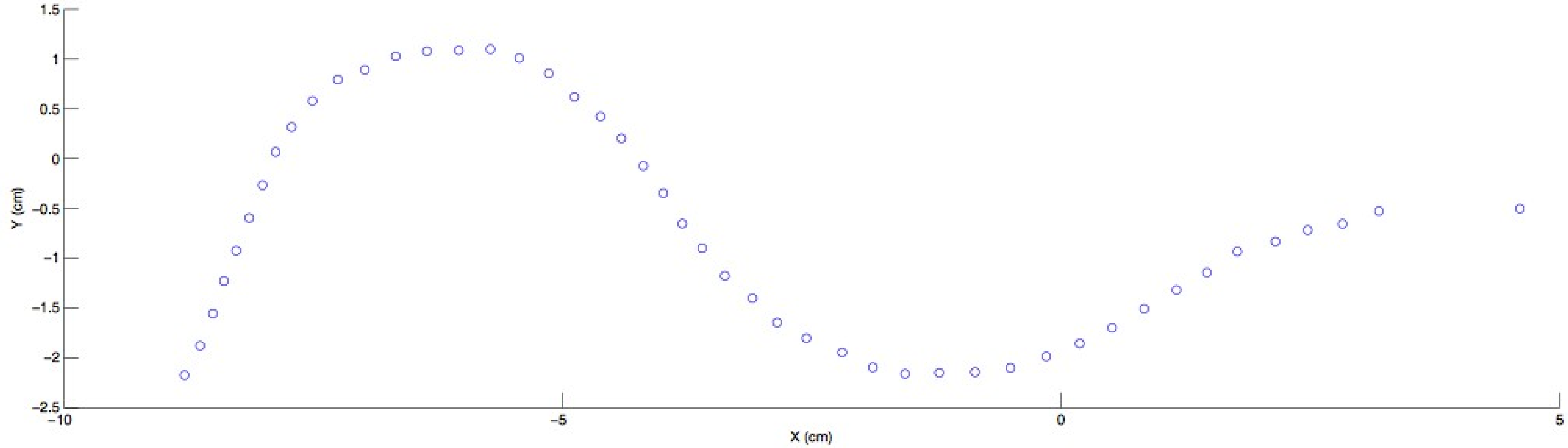


850
800
750
700
650
600
550
500
450
400
Y (px)
600
700
800
900
1000
1100
1200
X (px)

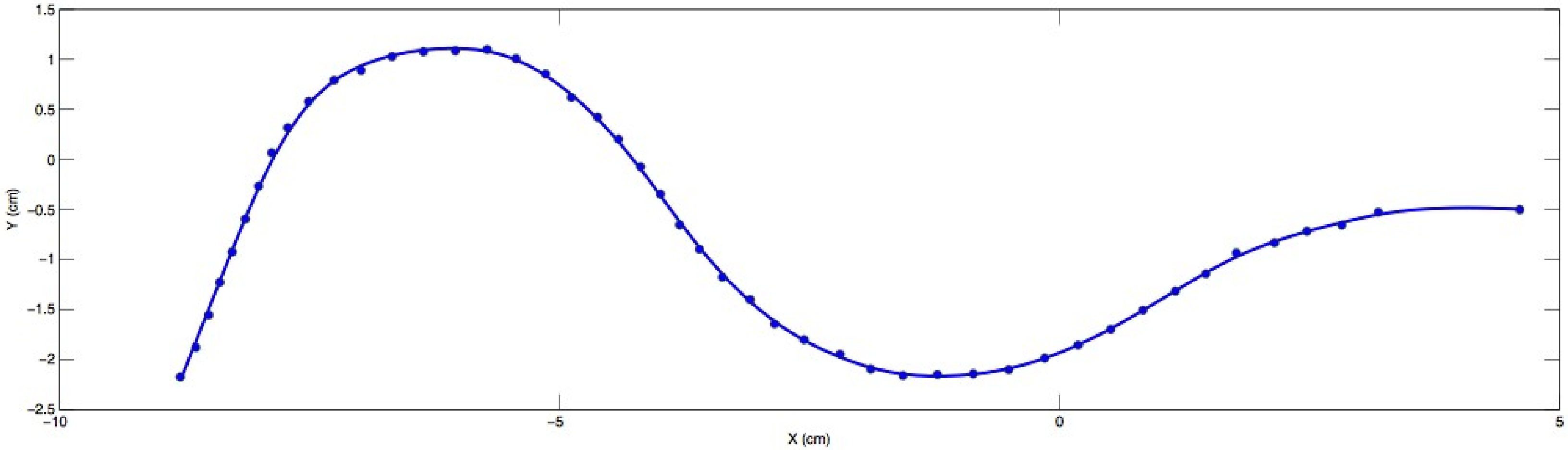
Kinematics



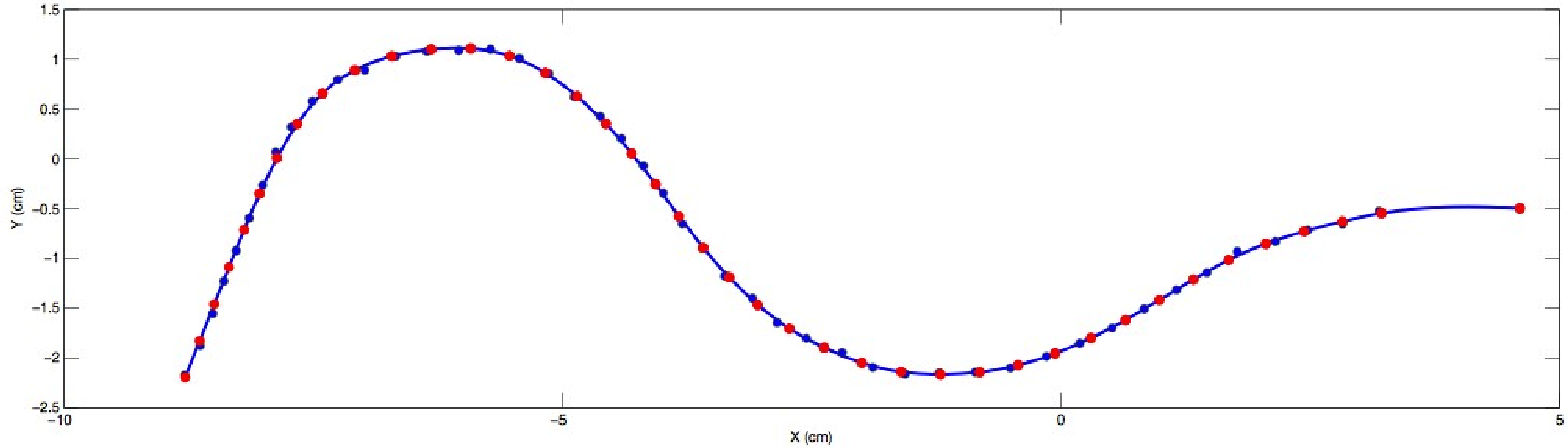
Kinematics



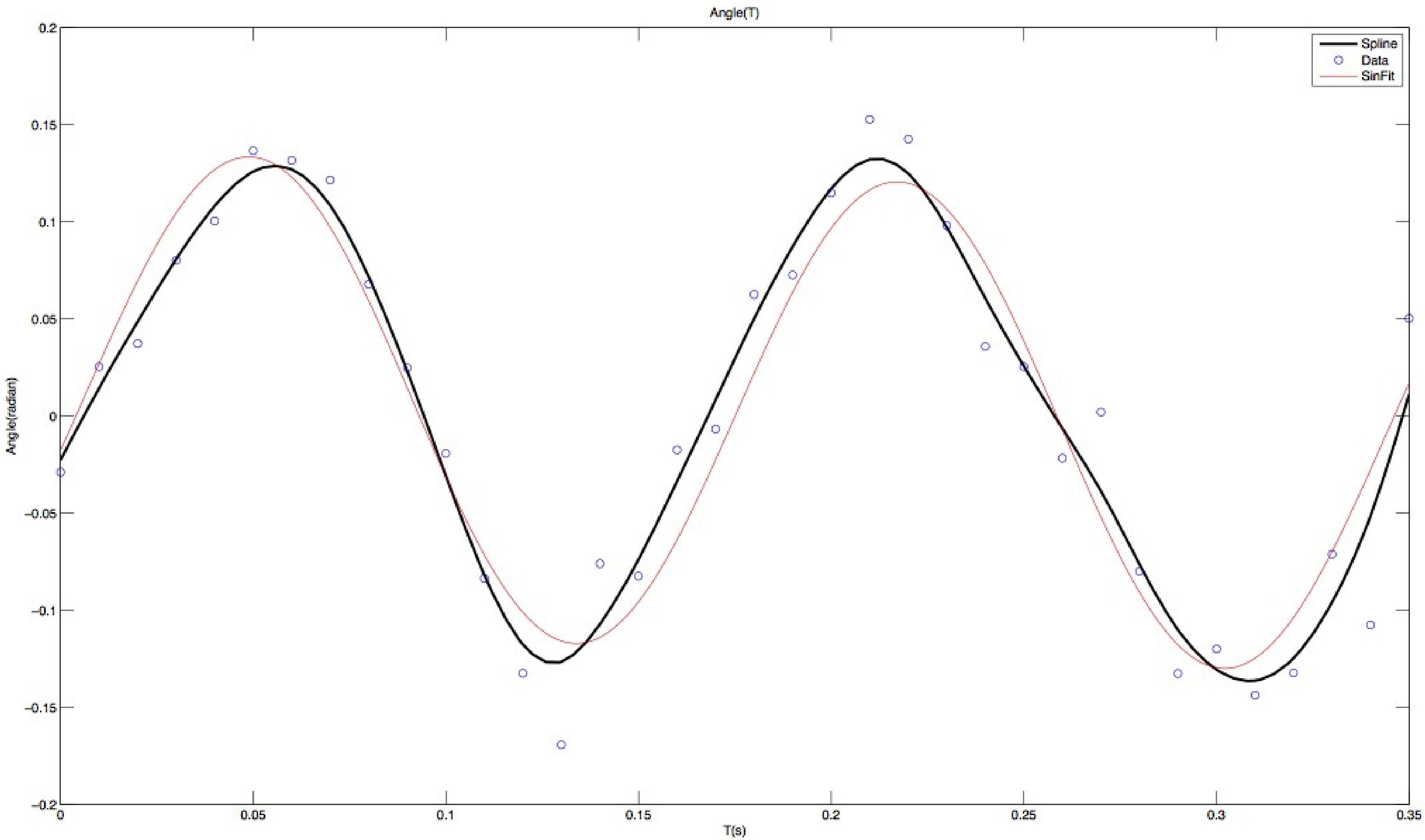
Kinematics



Kinematics

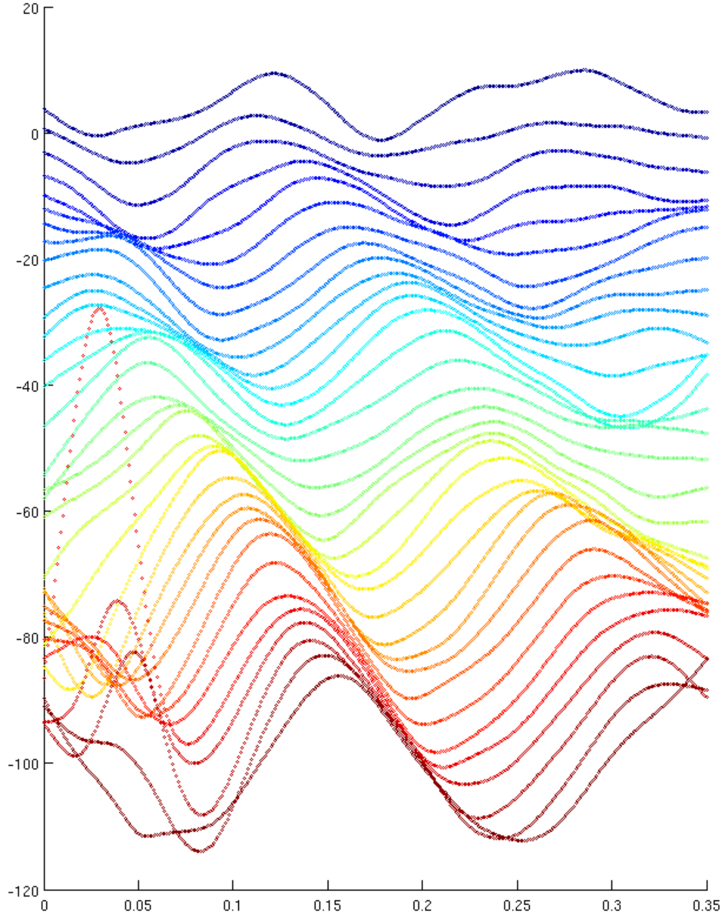


Kinematics

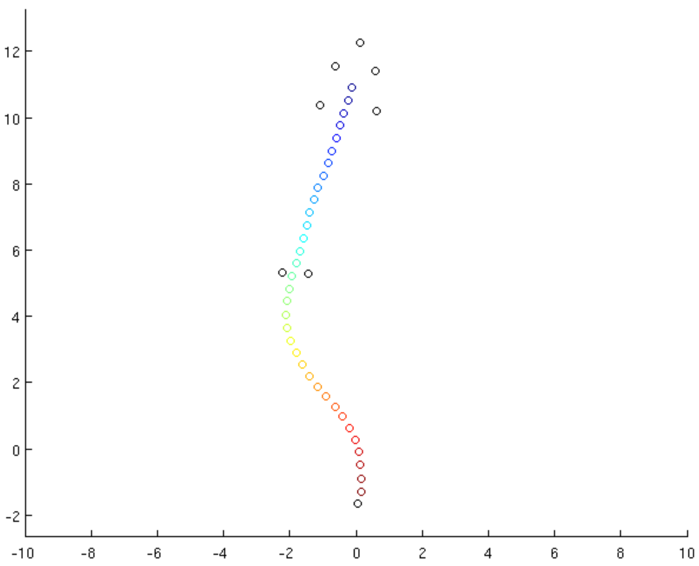


Angle(T)
Spline
Data
SinFit
Angle(radian)
T(s)
0.2
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
−0.2
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35

Kinematics

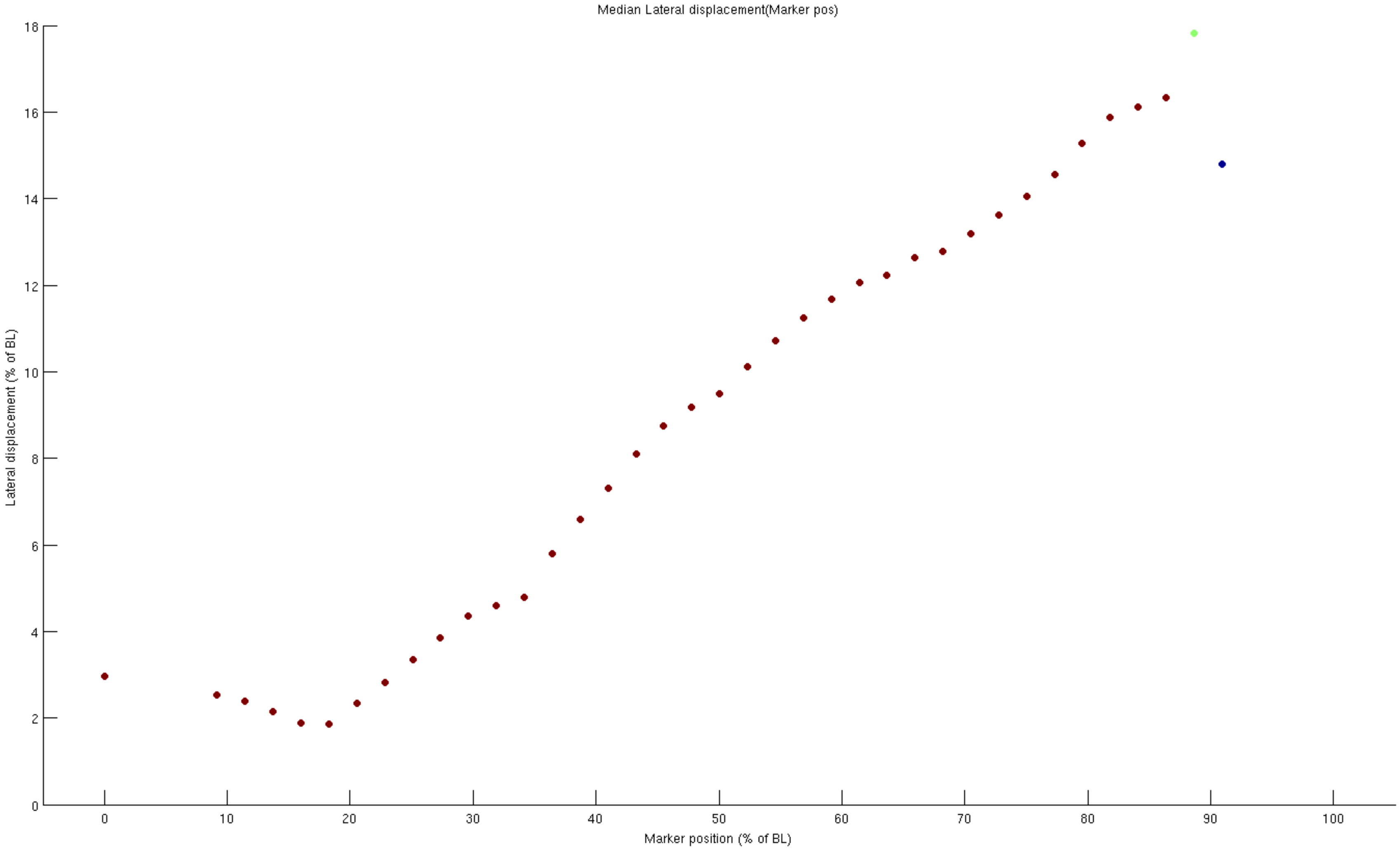


20
0
-20
-40
-60
-80
-100
-120
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35



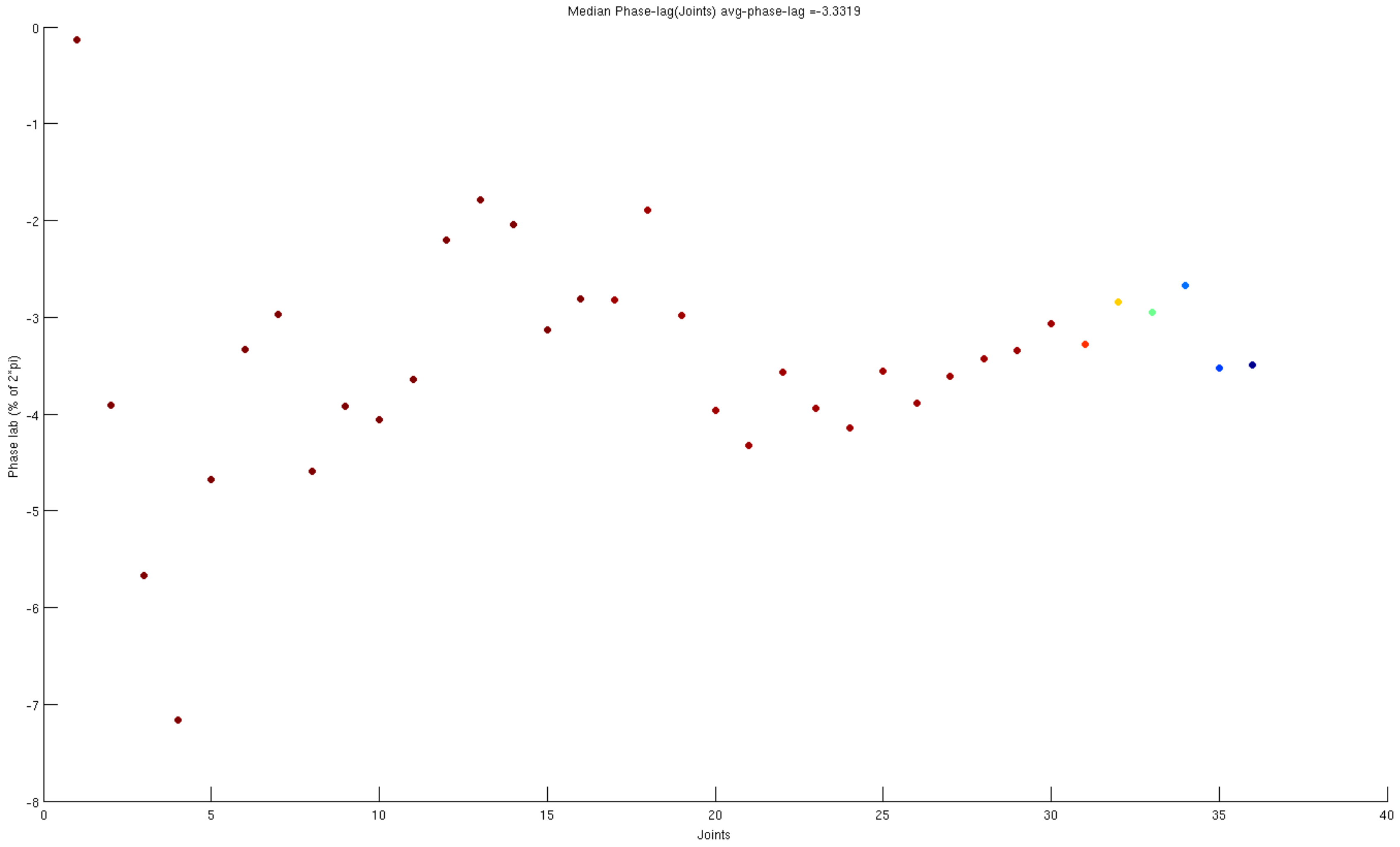
12
10
8
6
4
2
0
-2
-10
-8
-6
-4
-2
0
2
4
6
8
10

Kinematics



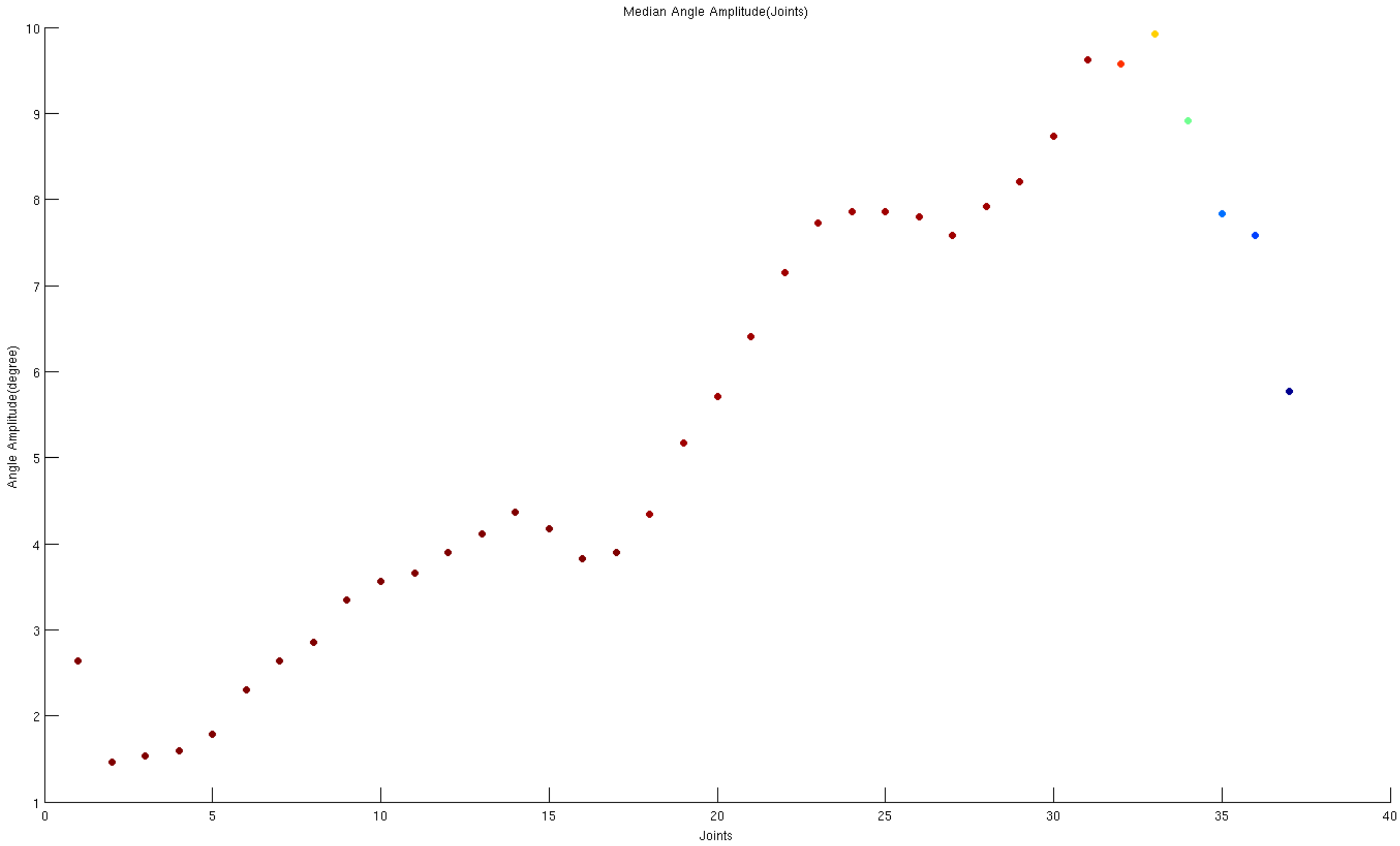
Median Lateral displacement(Marker pos)
Lateral displacement (% of BL)
Marker position (% of BL)
0
2
4
6
8
10
12
14
16
18
0
10
20
30
40
50
60
70
80
90
100

Kinematics



Median Phase-lag(Joints) avg-phase-lag =-3.3319
Phase lab (% of 2*pi)
Joints
0
-1
-2
-3
-4
-5
-6
-7
-8
0
5
10
15
20
25
30
35
40

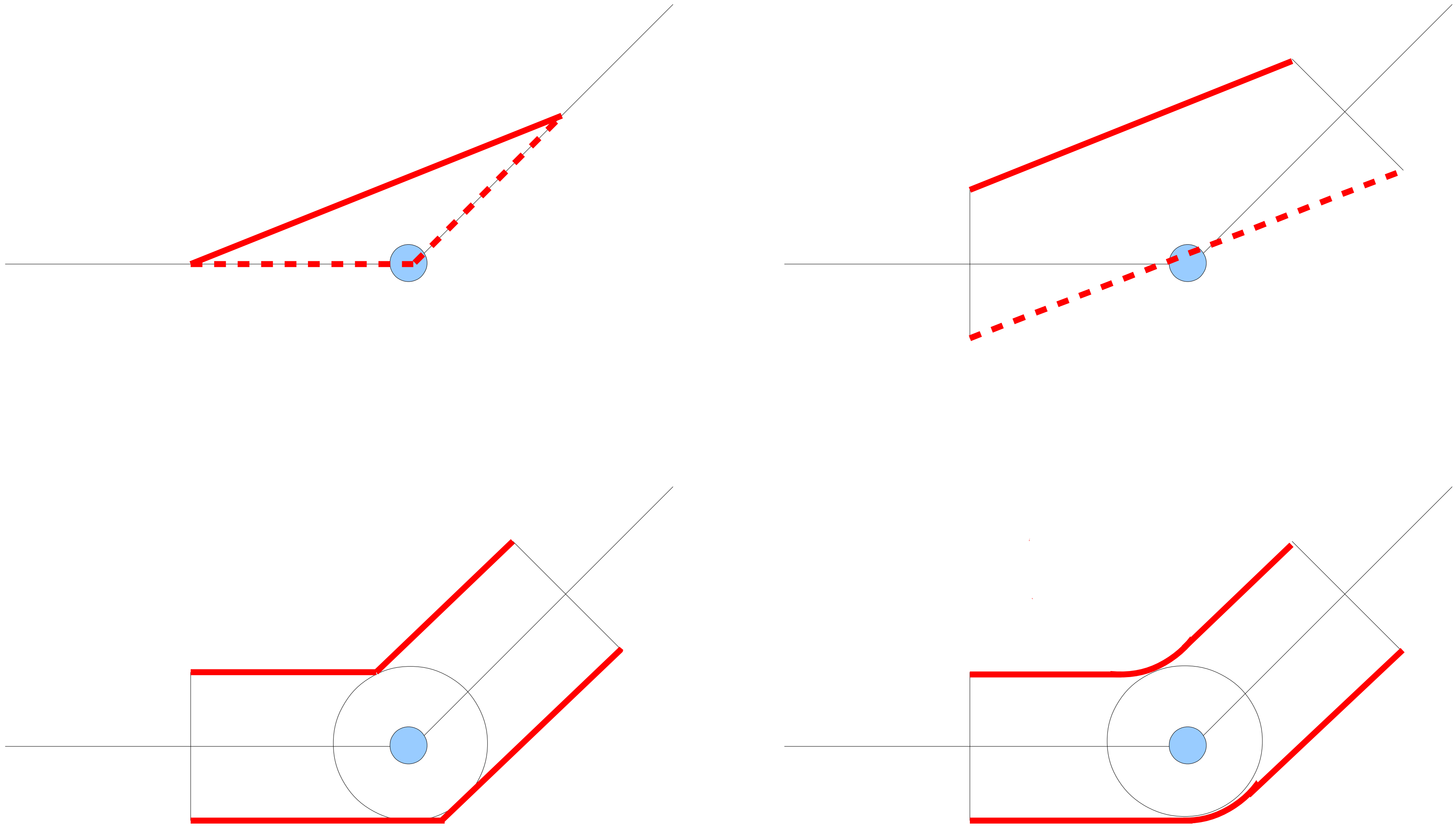
Kinematics



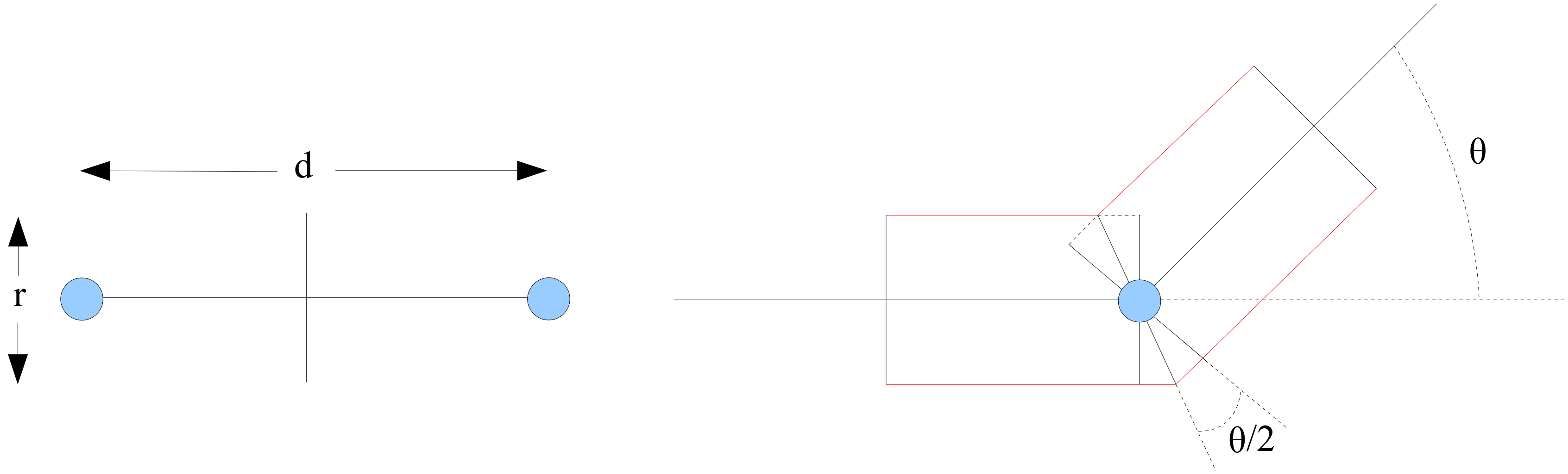
Median Angle Amplitude(Joints)
Angle Amplitude(degree)
Joints
10
9
8
7
6
5
4
3
2
1
0
5
10
15
20
25
30
35
40

Muscle/Joint model

Joint model

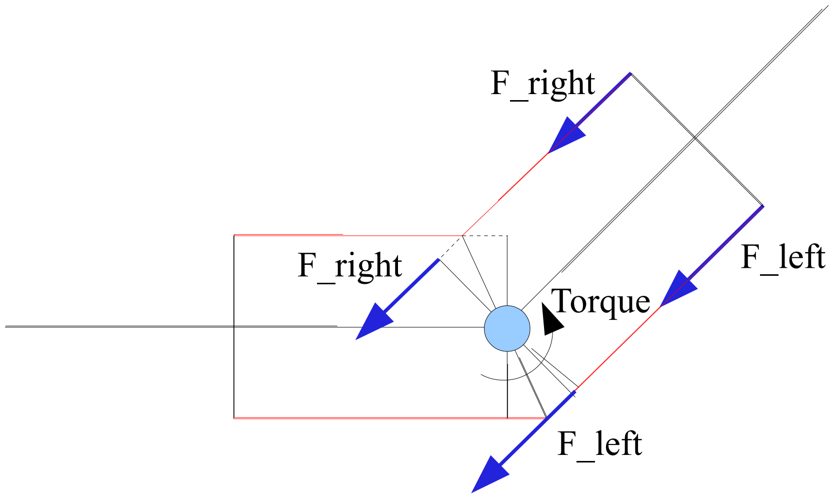


Joint model



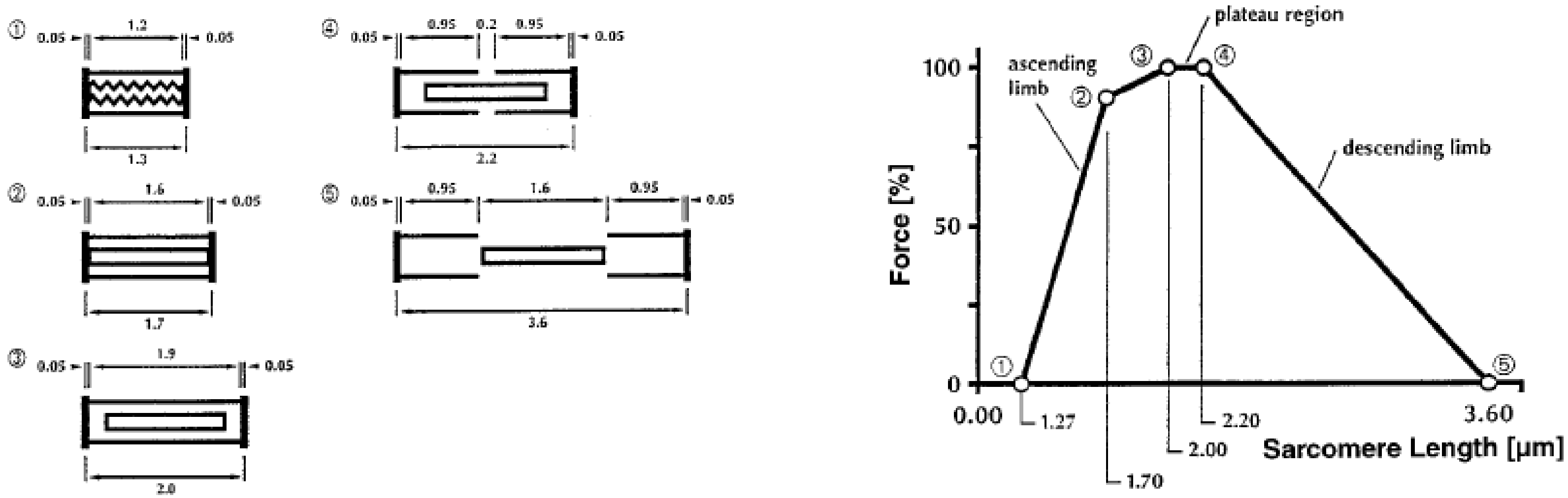
$$muscle\_length = d \pm r * \tan(\theta/2)$$

Joint model



$$Torque = (F\_right - F\_left) * (r/2)$$

Muscle model



Reference :
Length dependence of active force production in skeletal muscle
D. E. RASSIER, B.R MacINTOSH, AND W. HERZOG

Fig. 2. Force-length relationship of frog skeletal muscle sarcomere, as derived first by Gordon et al. (28) (*top*), and schematic sarcomeres corresponding to crucial points (*1–5*) labeled on the force-length curve (*bottom*).

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Muscle model

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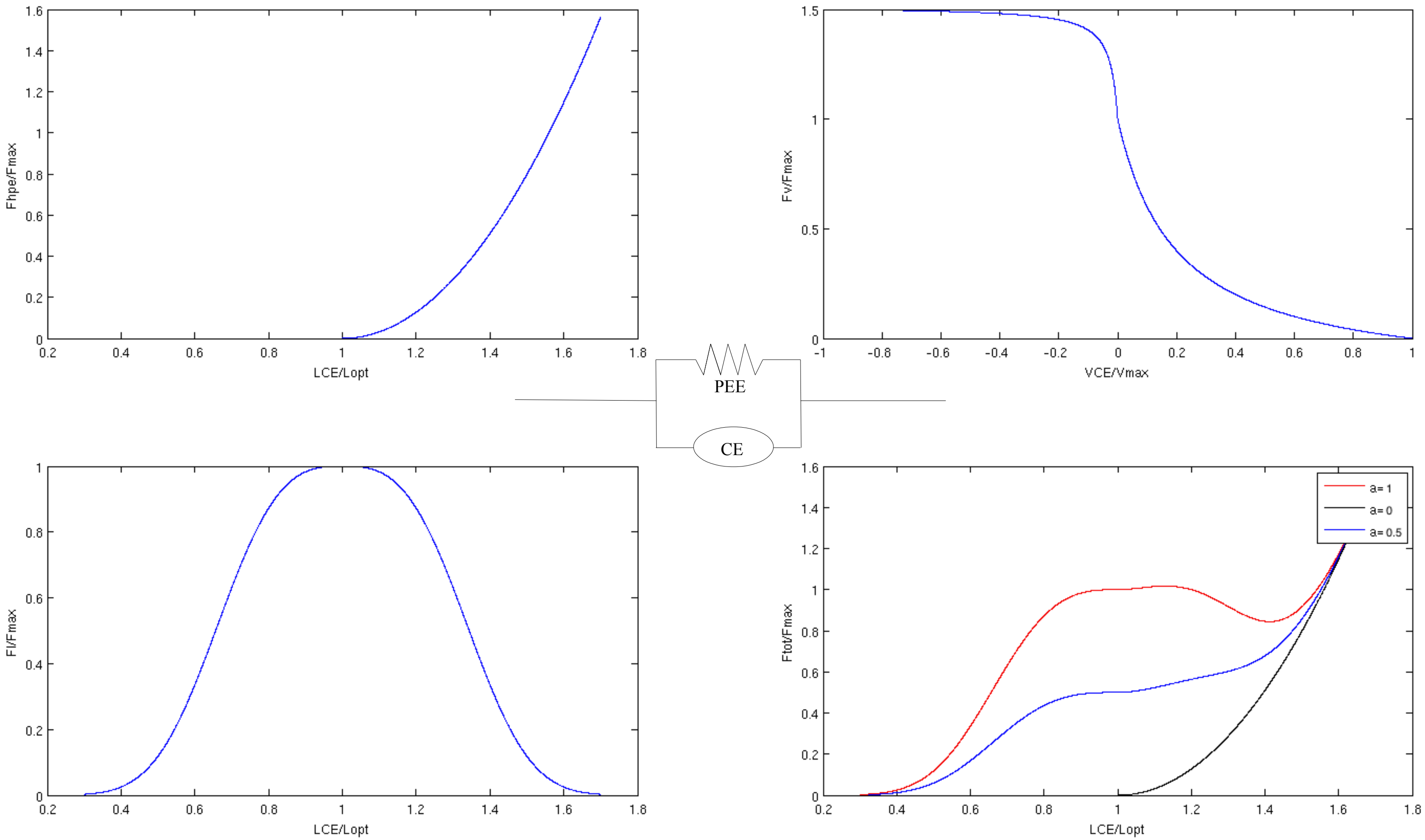
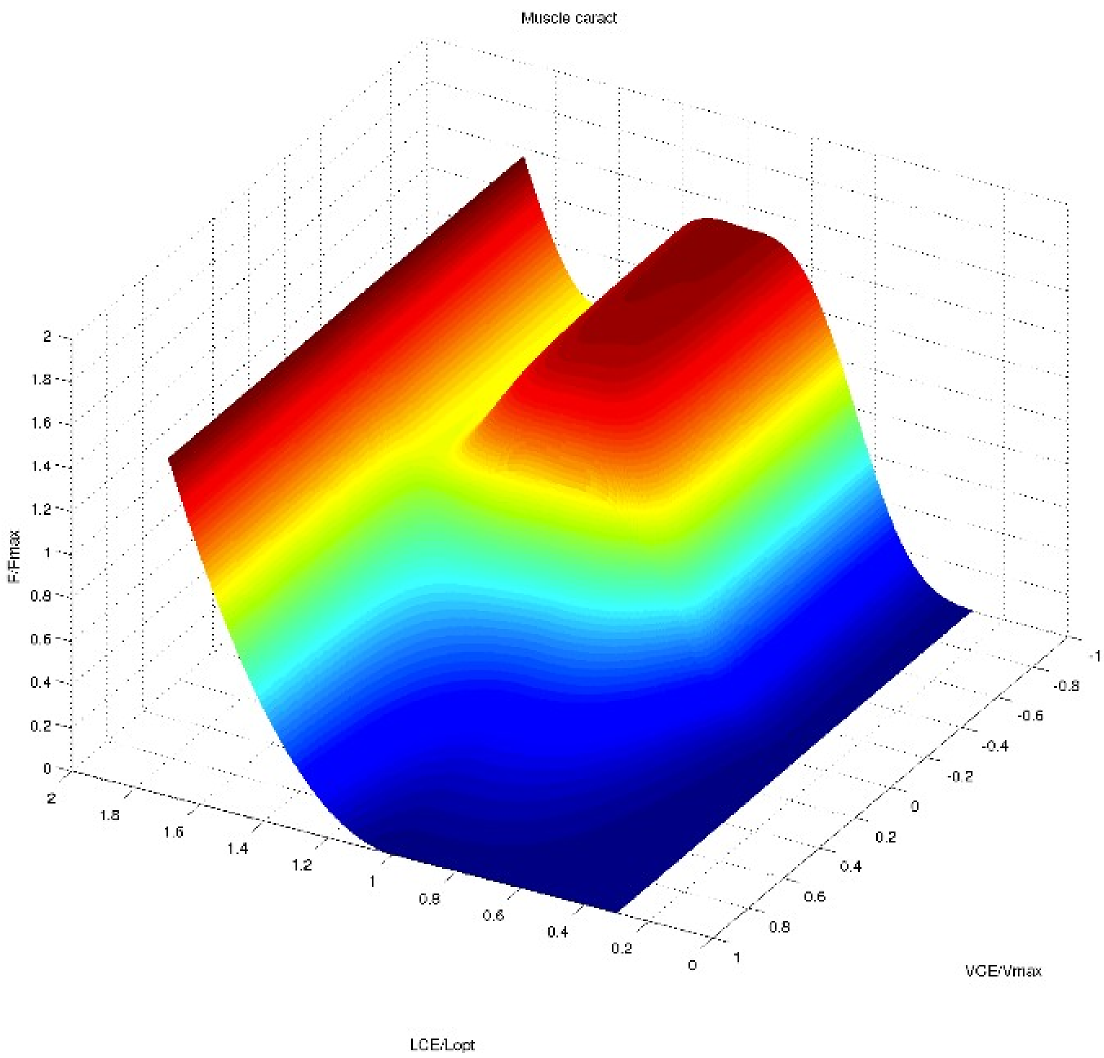


Ftot = Fmax * activation * Fl * Fv + Fppe

Muscle model



Muscle model

u(t) = electrical excitation (EMG)

a(t) = chemical excitation

$$\frac{da(t)}{dt}+\left[\frac{1}{Tact}\cdot\left(B+(1-B)\cdot u(t)\right)\right]\cdot a(t)=\left(\frac{1}{Tact}\right)\cdot u(t)$$

$$0<B=const<1$$

Reference :
Muscle and tendon : properties, models, scaling, and application
to biomechanics and motor control
Felix E. Zajac

Metabolic cost

$$dE = dH + dW$$

$$dH = dA + dM + dS + dB$$

> dA = Φ * m * a(t) * AHR

Φ = 0.06 + exp(- tstim * a(t) / 0.045)

> dH = L(lm) * m * a(t) * MHR

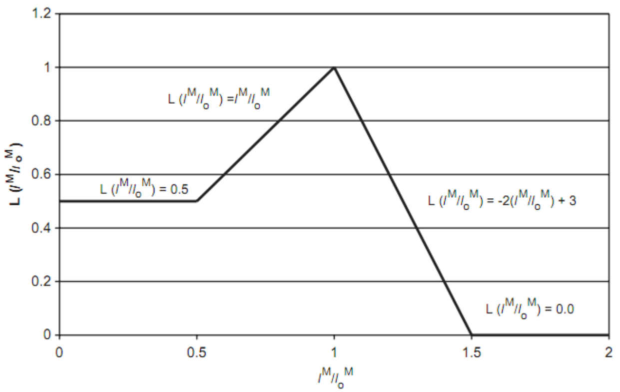


Fig. 2. Length dependence of the maintenance heat rate. The function $L(l^{M}/l_{o}^{M})$ is used for approximating the maintenance heat rate $\dot{M}$ (Eq. (7)).

> dS = α * Vce

If shortening :

α = 0.16 F_iso + 0.18 F

Else

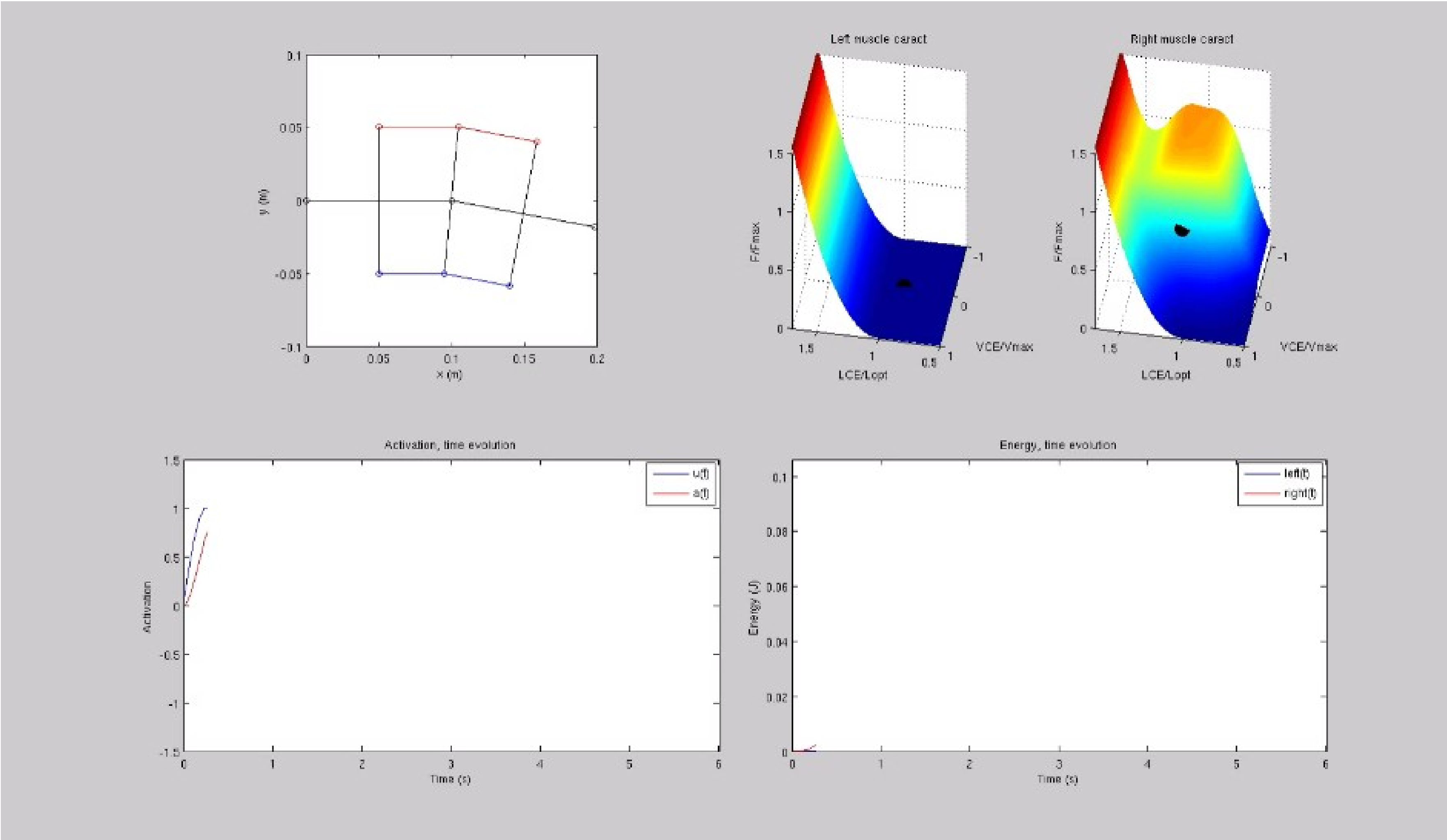
α = 0.157 * F

> dB = 0.0225 * m

> dW = F * Vce

Reference :
A phenomenological model for estimating metabolic energy consumption in muscle contraction
Lindsay J. Bhargava, Marcus G. Pandy, Frank C. Anderson

Test bed



Left muscle caract
Right muscle caract
F/Fmax
VCE/Vmax
LCE/Lopt
y (m)
x (m)
Activation, time evolution
Activation
u(t)
a(t)
Time (s)
Energy, time evolution
Energy (J)
left(t)
right(t)

Test bed

Summary

Activation : Tact , B , G

Muscles : Fmax , Lopt , Vmax

Joints : r

Objectives :
- match the kinematics
- minimize the metabolic cost

Coming soon

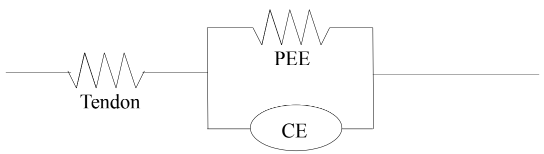
EMG & kinematics synchronization

Fitting function = fct(matching,energy,r)

Optimization

Direct use of kinematics data with the robot

Add tendon



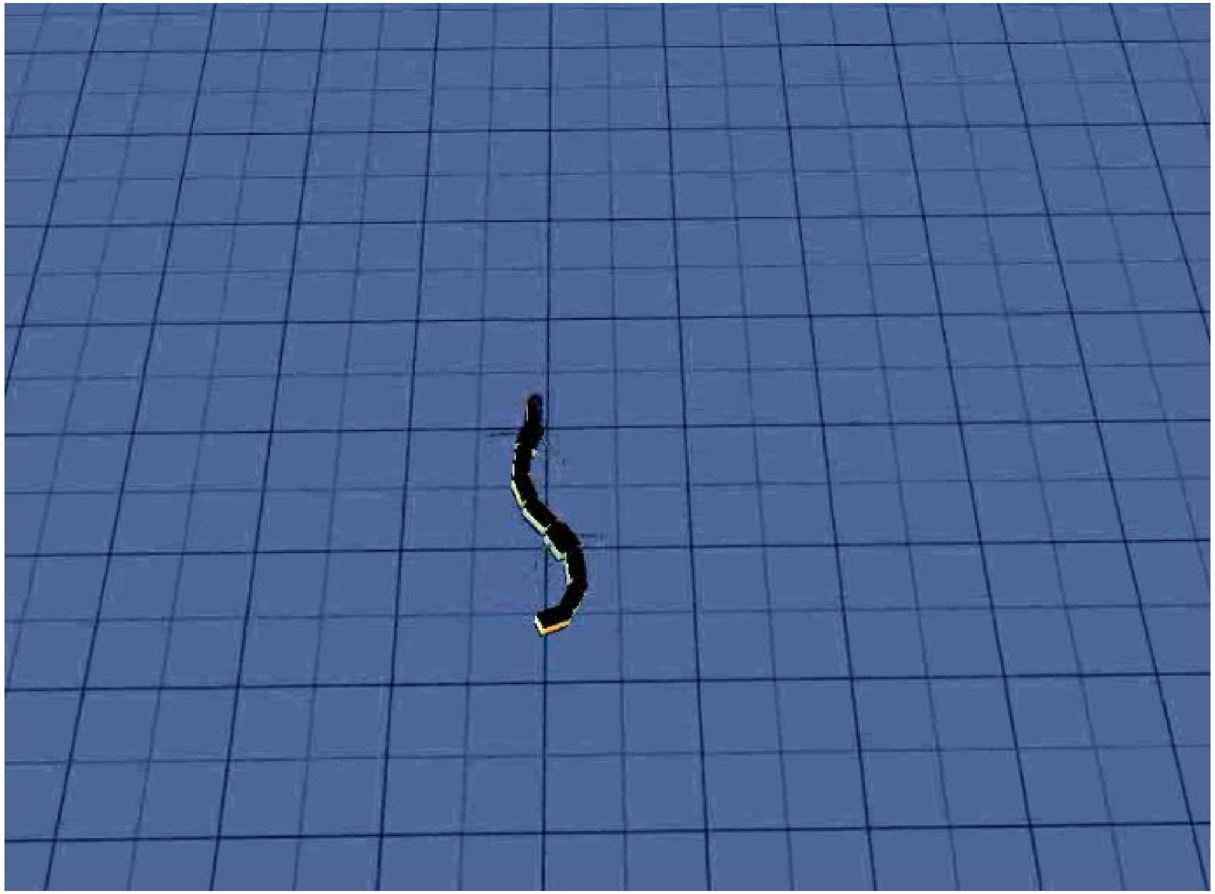
Bonus

Differentiate slow and fast muscles

Optimization of EMG for speed

40 segment model with biological data

Webots



Webots

Thank you for your time

Any questions?