Simulation of Muscle Reflex Control System And Observing the Implication of Positive Feedback in the Control of Movement

Presented By:

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Introduction

Generally in our body →

Negative Feedback System
(Muscle response opposes change)

- Force feedback loop tends to hold force constant in face of disturbances.
- Displacement feedback loop tends to hold length constant.

Where does Positive Feedback System work?

In load-bearing tasks such as locomotion

In Positive Feedback System: Signals from force-sensing afferents **reflexly increase the force the receptors** sense

Introduction

Positive Feedback System Example

In spinal and decerebrate cats, heteronymous reflexes mediated by tendon organ Ib afferents switch **from being inhibitory in static postures to excitatory during locomotion**

But Positive Feedback Systems show INSTABILITY

The paper **verifies the stability of positive feedback system**:

- For gain between 0 to 1 (Between this range the loop gain automatically becomes attenuated when muscles actively shorten and reduce their force producing capability)
- Addition of reflex delay stabilizes the system

Control System

Muscle Reflex Model

Simple Reflex Model

Neglected:

- Length and Velocity Dependence of Muscle Force Production
- Tendon Compliance
- Dynamic Transfer Functions

Non-Linear Reflex Model

Included:

- Length-Tension and Force Velocity Relationships are represented
- Tendon Compliance Included
- Viscoelastic Stiffness Included

Literature Used for Model Reference: Implications of Positive Feedback in the Control of Movement
(https://journals.physiology.org/doi/full/10.1152/jn.1997.77.6.3237)

Modelling of Elements

Source of Model:
https://journals.physiology.org/doi/full/10.1152/jn.1997.77.6.3237

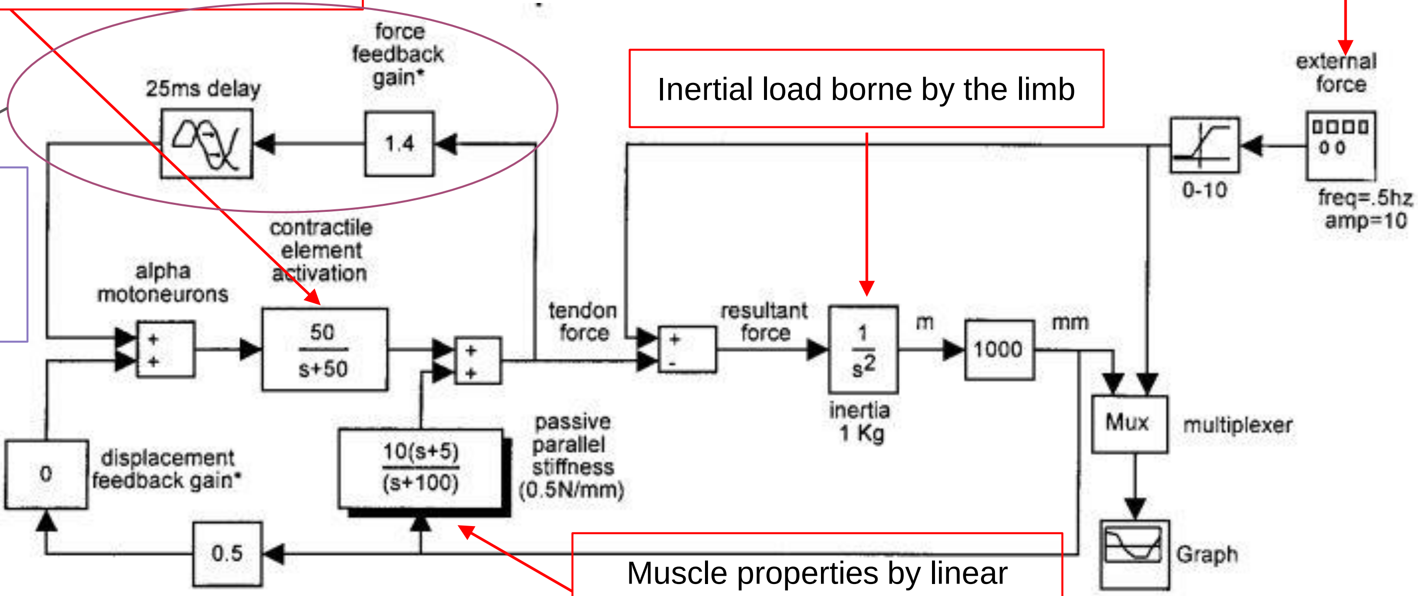
Simple Reflex Model

Muscle Contractile Element: First Order Low Pass Filter with a cutoff freq of 8Hz

Mean force developed by triceps surae during stance phase of slow gait

Positive Force Feedback

Inertial load borne by the limb

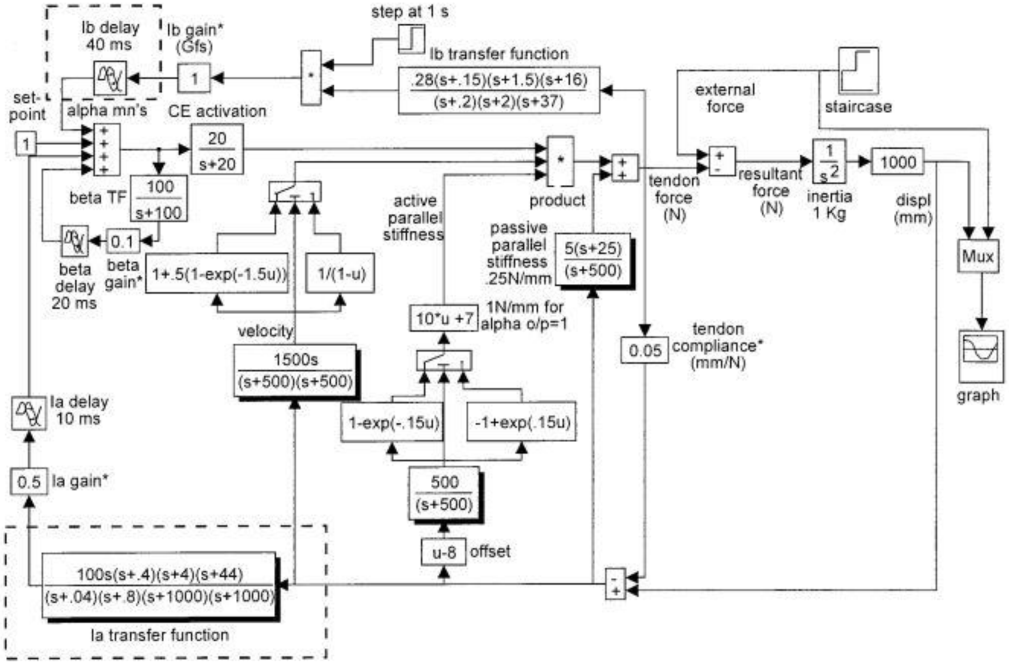


Muscle properties by linear viscoelastic stiffness

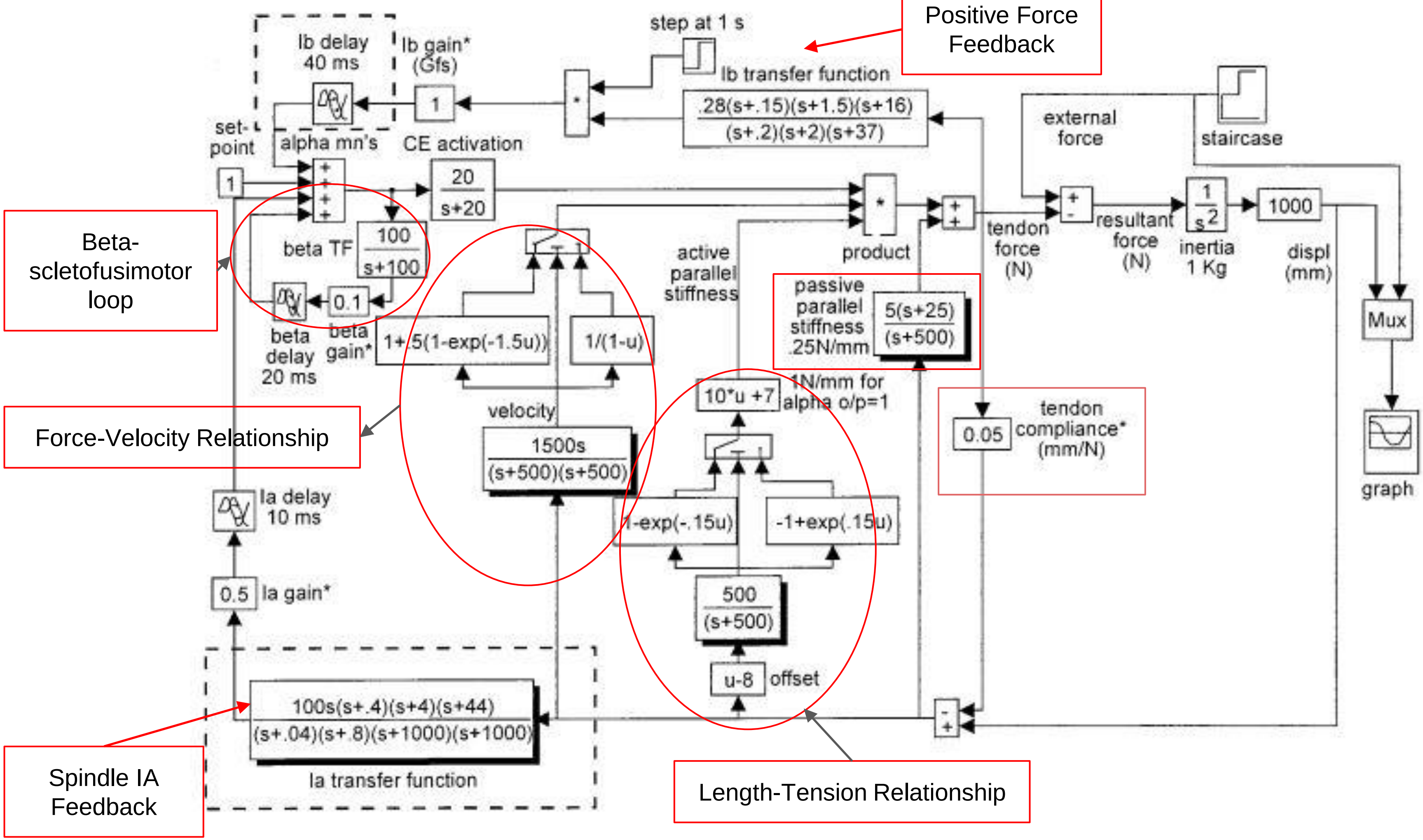
Modelling of Elements

Source of Model:
https://journals.physiology.org/doi/full/10.1152/jn.1997.77.6.3237

Non-Linear Reflex Model



Source of Model: https://journals.physiology.org/doi/full/10.1152/jn.1997.77.6.3237



- The contractile element is modeled as a first-order low-pass filter with a cutoff frequency of 3.2 Hz. Feedback via the series (tendon) compliance adds a second pole, also at 3 Hz

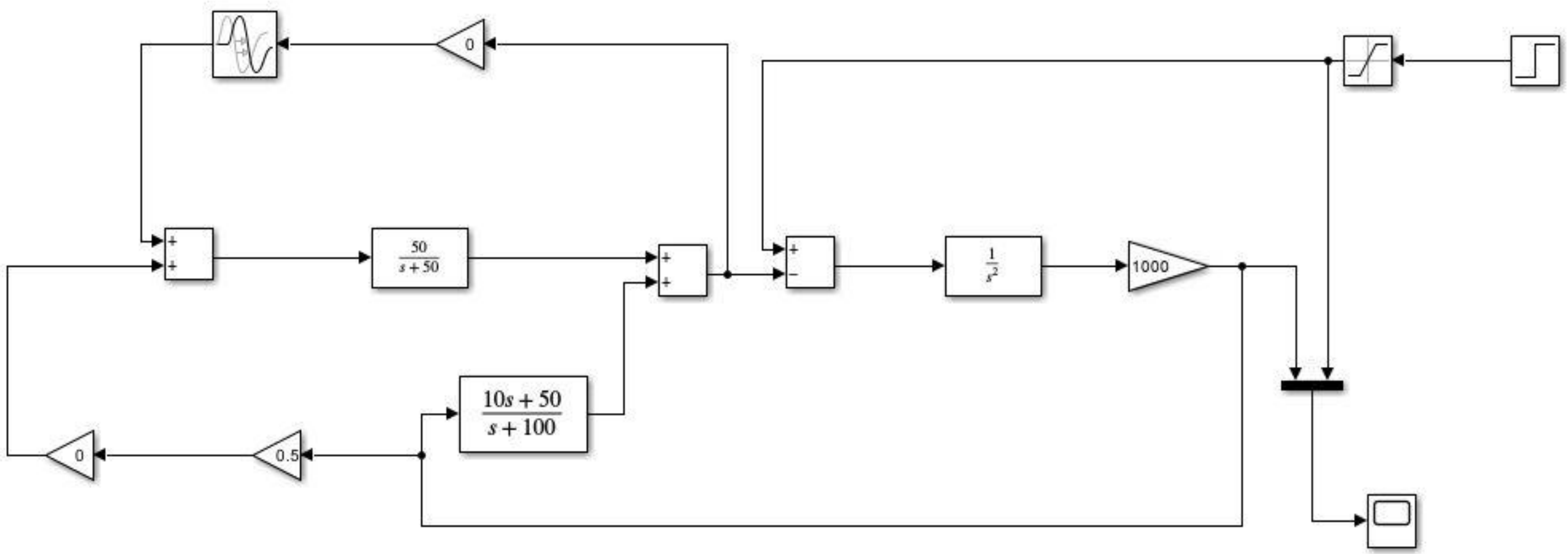
- The length-tension curve is a sigmoidal relationship made up of two exponential functions

- The force-velocity curve made up of a Hill-type hyperbolic function for negative (shortening) velocities and an exponential function for positive and and an exponential function for positive (stretch) velocities

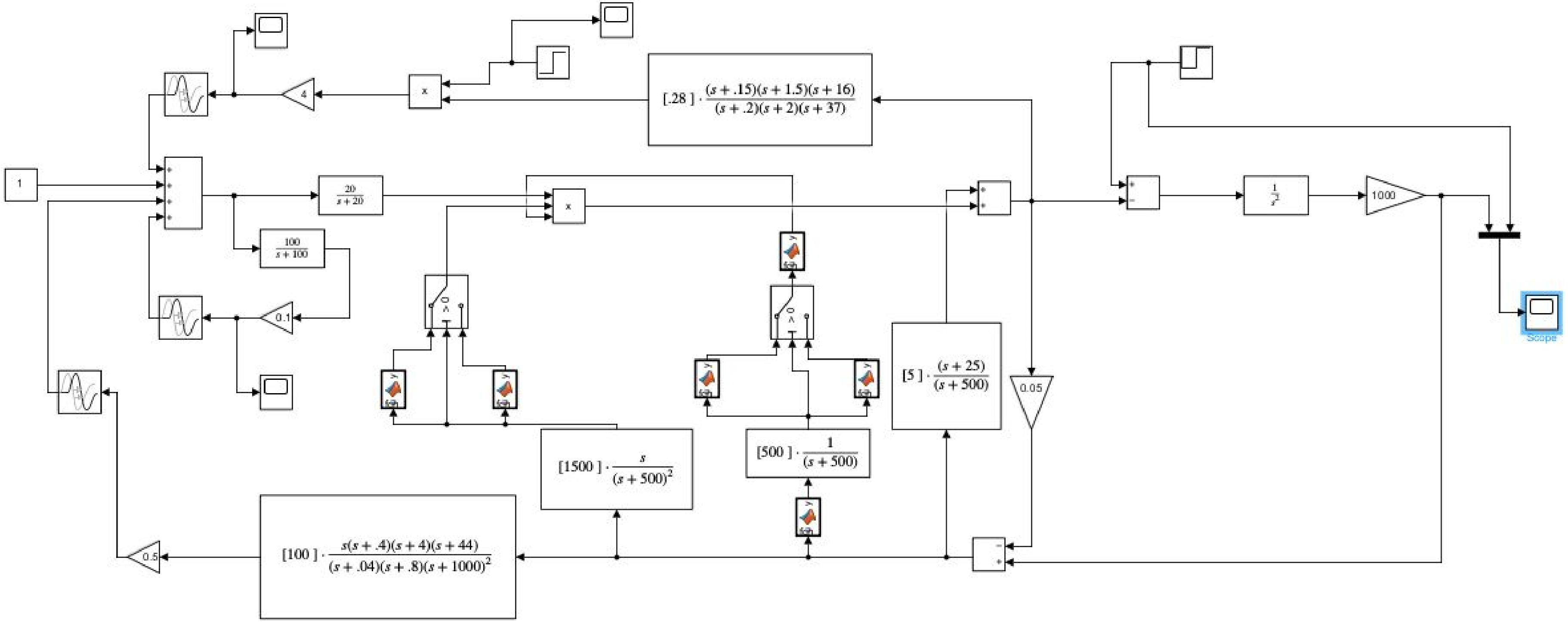
- Force Feedback and spindle IA feedback represented by a linear transfer function

Constructed Simulink Model

Simple Reflex Model

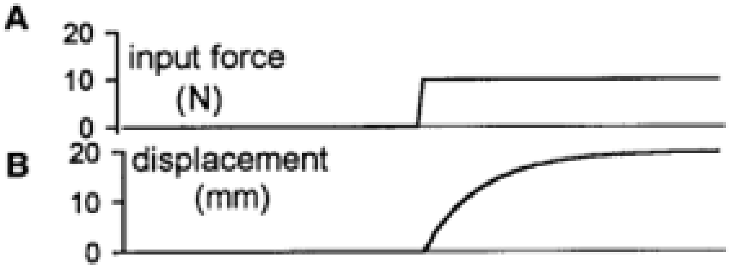


Non-Linear Reflex Model

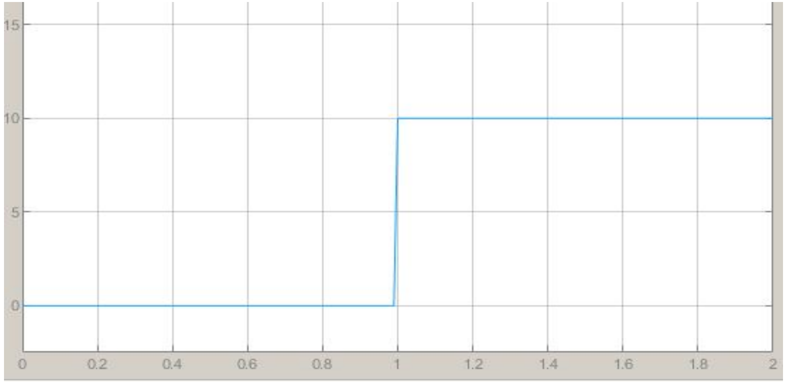


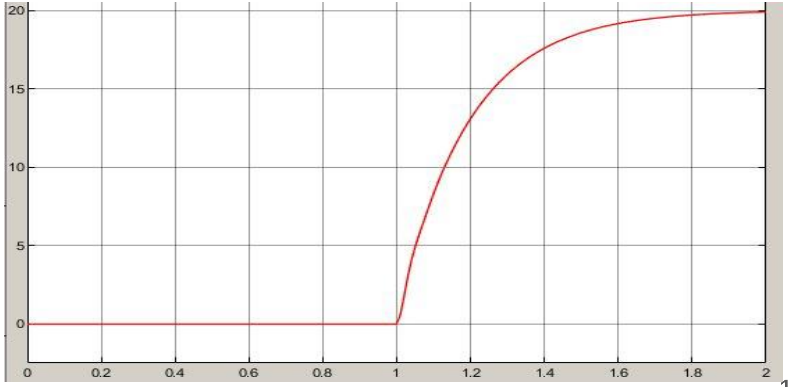
Results

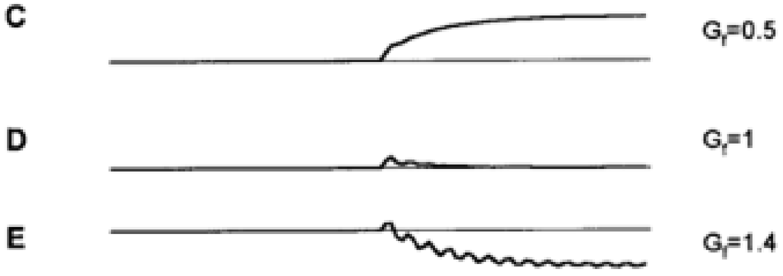
Simple Reflex Model

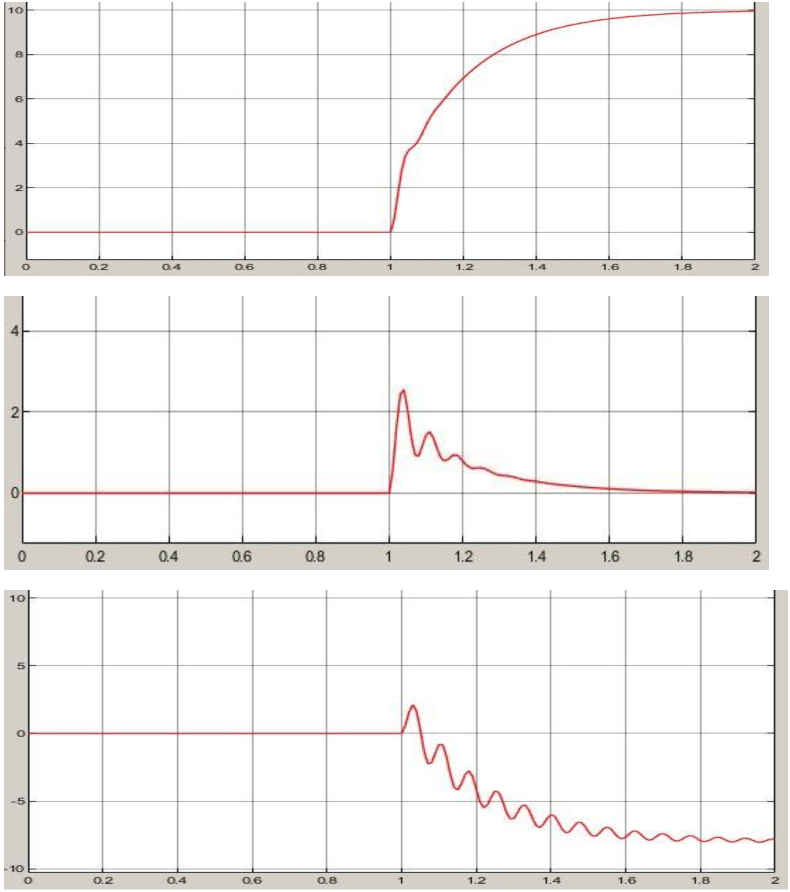


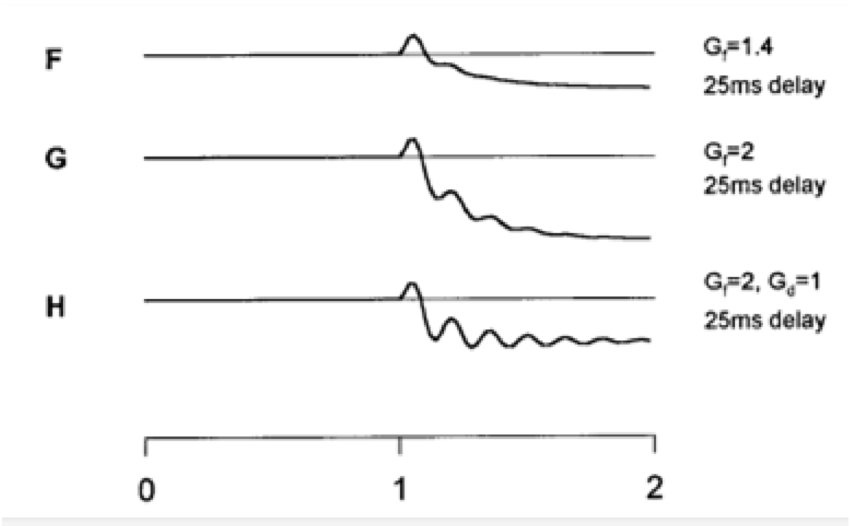
no feedback

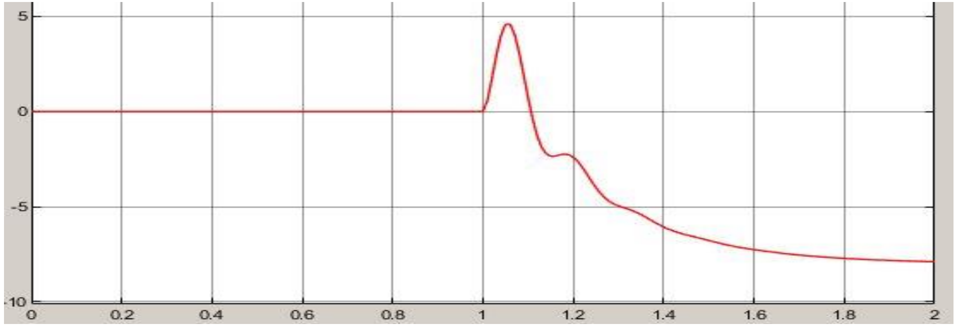




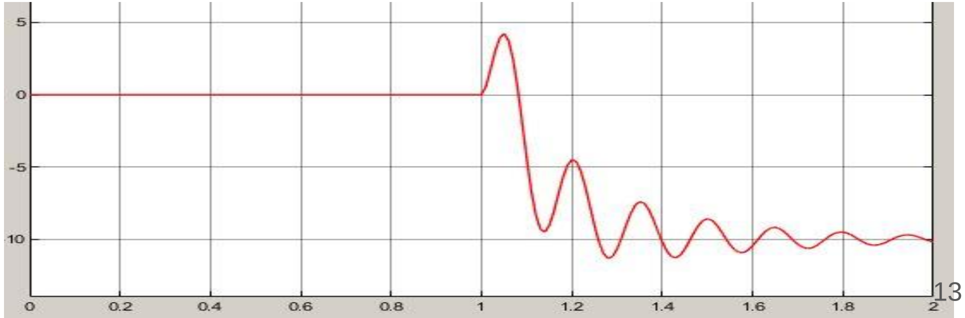

C
D
E
G_f=0.5
G_f=1
G_f=1.4


10
8
6
4
2
0
0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2
4
2
0
0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2
10
5
0
-5
-10
0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2

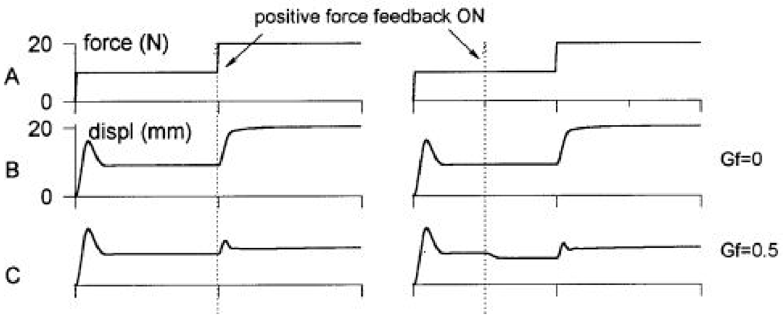

F
G
H
G_f=1.4
25ms delay
G_f=2
25ms delay
G_f=2, G_d=1
25ms delay
0
1
2

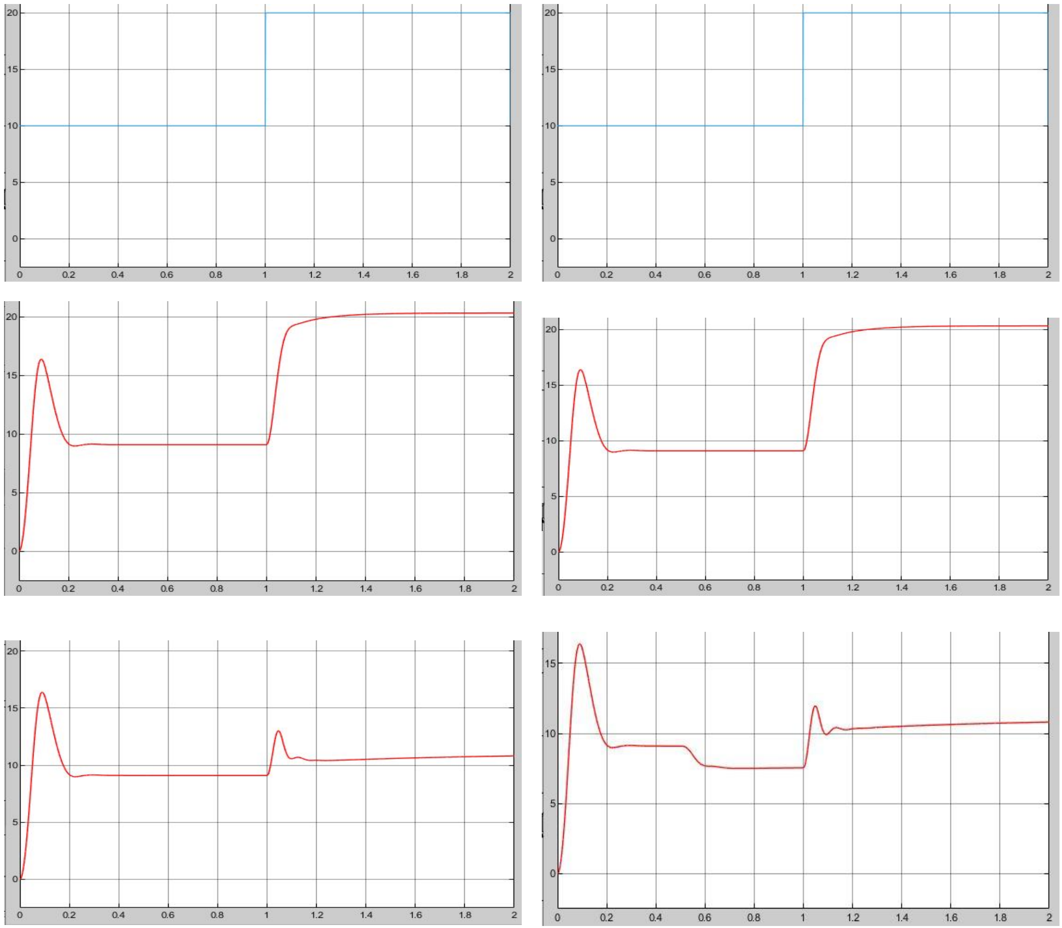

5
0
-5
-10
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2

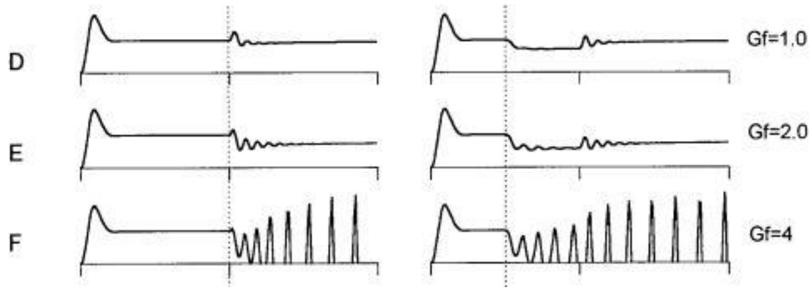

5
0
-5
10
15
20
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2

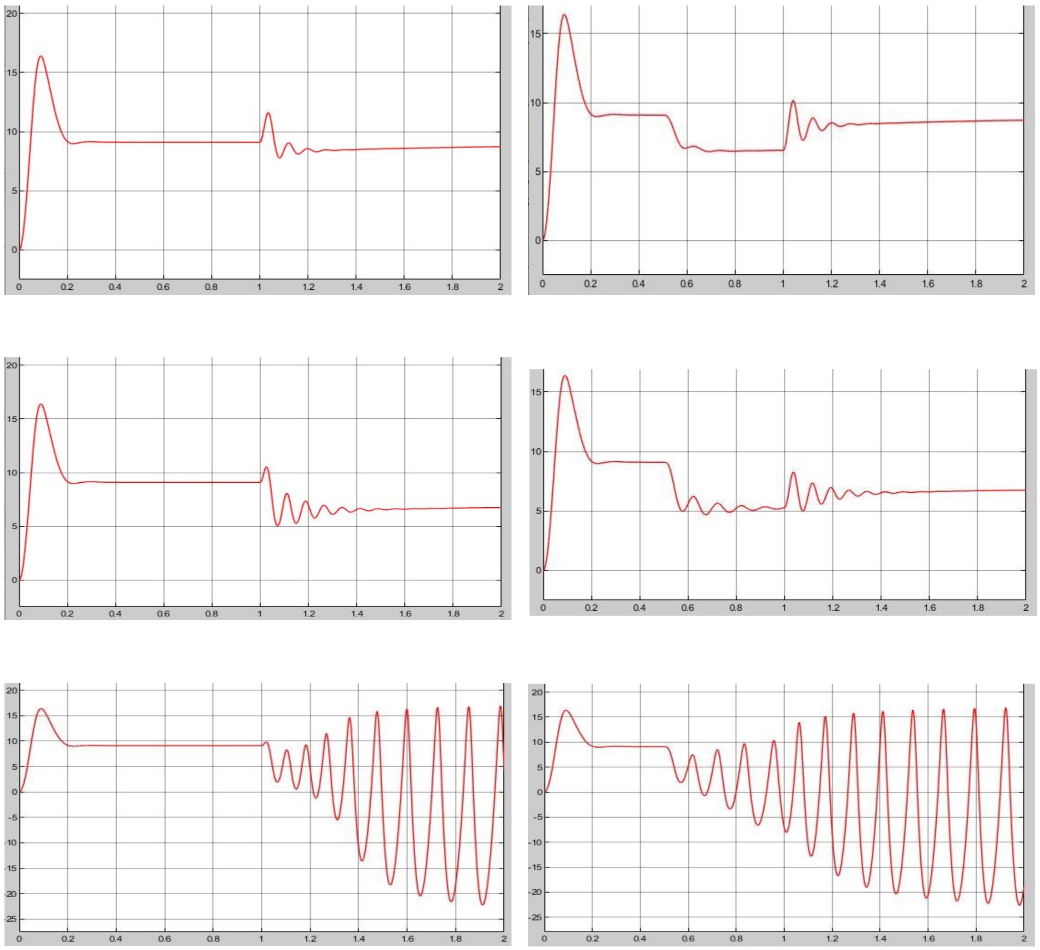

5
0
-5
10
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2

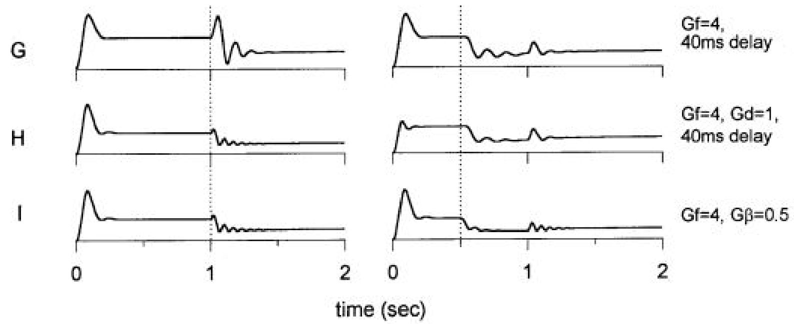
Non-Linear Reflex Model

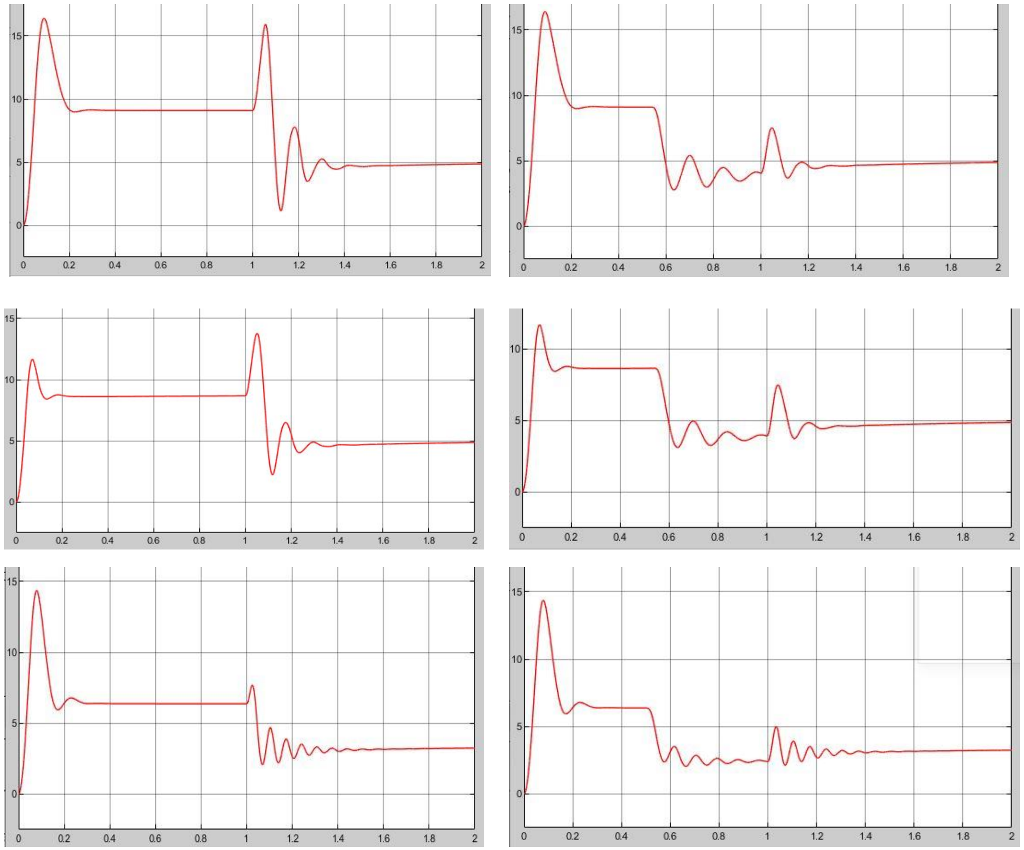





D
E
F
Gf=1.0
Gf=2.0
Gf=4




G
H
I
Gf=4,
40ms delay
Gf=4, Gd=1,
40ms delay
Gf=4, Gβ=0.5
0
1
2
0
1
2
time (sec)



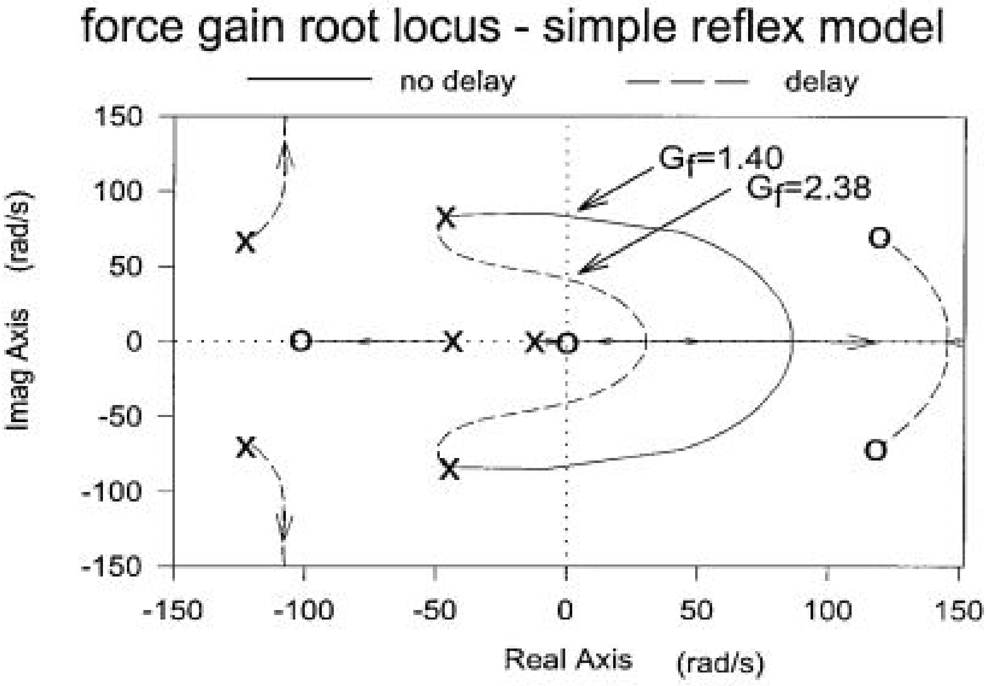
Conclusions

This analysis provides the conclusion that that positive force feedback confers useful load compensation in case of animal movement.

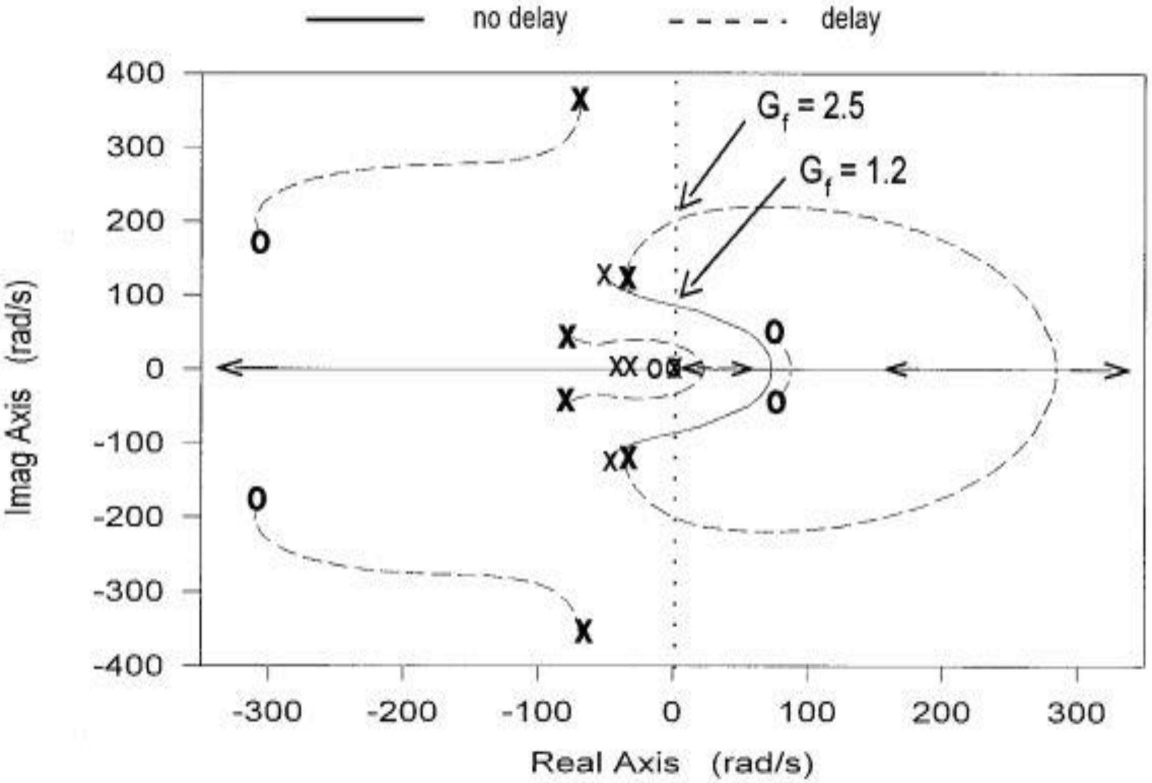
Delays and displacement gains provide stabilizing influences.

THANK YOU

Appendix



force gain root locus - simple reflex model
no delay
delay
Gf=1.40
Gf=2.38
150
100
50
0
-50
-100
-150
Imag Axis (rad/s)
-150
-100
-50
0
50
100
150
Real Axis (rad/s)



no delay
delay
400
300
200
100
0
-100
-200
-300
-400
Imag Axis (rad/s)
-300
-200
-100
0
100
200
300
Real Axis (rad/s)
G_f = 2.5
G_f = 1.2