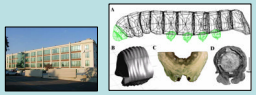
TUFTS UNIVERSITY

New challenges in biorobotics:
incorporating soft tissue into control systems

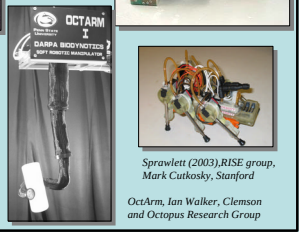
Barry Trimmer
Tufts Biomimetic Devices Laboratory
Tufts Biology Department, USA



Flexibility in robots

Robot V (2003), Daniel Kingsley, Roger Quinn, CWU

Crespi, A., Badertscher, A., Guignard, A. and Ijspeert, A. J.



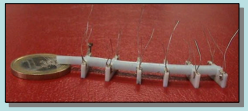
Murata Satoshi, Tokyo Institute of Technology

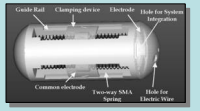
Sprawlett (2003),RISE group, Mark Cutkosky, Stanford

OctArm, Ian Walker, Clemson and Octopus Research Group

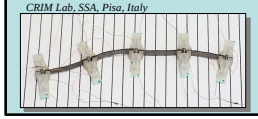
Soft material robots

Kim, Lee, Park and Park
Intelligent Microsystems Center, Korea





CRIM Lab, SSA, Pisa, Italy



Tufts Biomimetic Devices Lab, USA

How are soft materials accounted for, and used by, the control system?

- Soft-bodied, legged locomotion in *Manduca*
- Muscles as multi-state materials
- Neural control of locomotion and muscle state
- Using soft materials in robot design

Soft materials in locomotion

- Soft-bodied, legged locomotion in *Manduca*
- Muscles as multi-state materials
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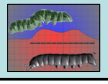
1

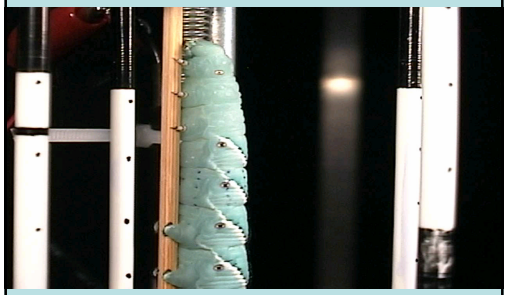
Caterpillar locomotion - a new model system

- Locomotion is ***very versatile*** (climbing in complex branched environments, burrowing) but ***stereotypical and slow*** (easy to capture and analyze)
- Muscles are ***discrete functional elements*** not “antagonistic blocks” organized very similar to adult arthropods and vertebrates
- ***Direct CNS to muscle relationship***, 1 MN per muscle, muscles are mapped, all major motoneurons identified. All sensory neurons are peripheral.
- ***Modular organization*** of segments (simplifies analysis)
- ***Completely soft-bodied***, stiff hooks used for gripping but not for any other other part of the locomotion
- ***Scalable*** (mass changes during growth 10,000 fold)



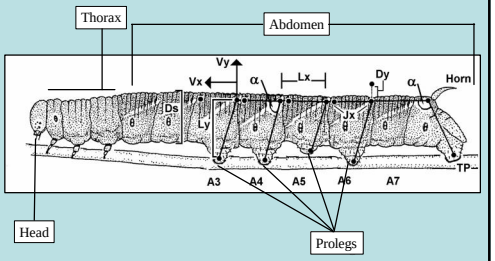
1

1



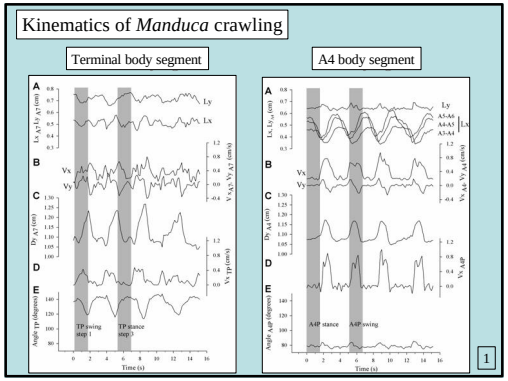
1

Kinematics of soft-bodied movements



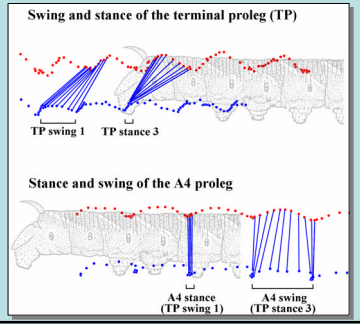
1

Kinematics of *Manduca* crawling



1

Different modes in different segments



1

Soft materials in locomotion

- Soft-bodied, legged locomotion in *Manduca*
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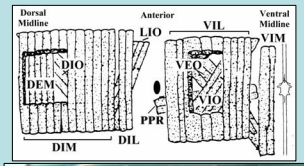
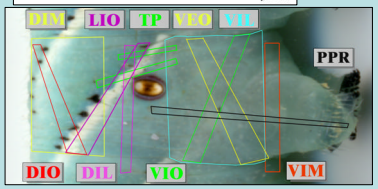
- Using soft materials in robot design

2

Mapping segmental muscles in *Manduca*

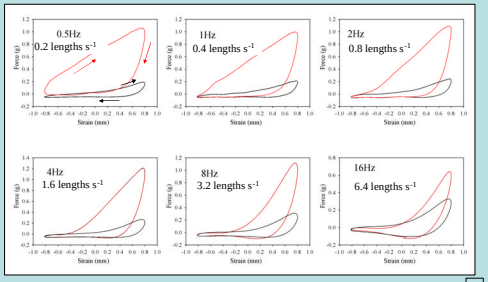




2

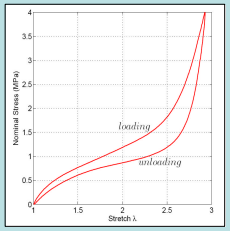
VIL, sinusoidal work loops, 0.25 to 8 Hz

? passive ? under tetanic 30 Hz stimulus

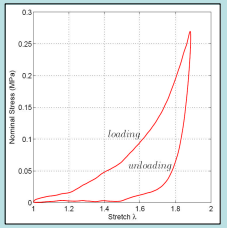


2

Constant velocity uniaxial loading and unloading (pseudoelastic responses)



Pre-conditioned carbon-black reinforced natural rubber specimen

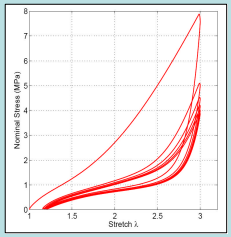


Pre-conditioned *Manduca* muscle (VIL)

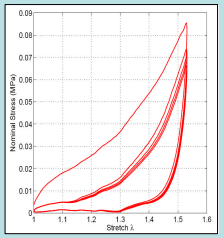
From: Dorfmann, A., Trimmer, B. A. and Woods, W. A., Jn. (2006). A constitutive model for muscle properties in a soft bodied arthropod. *J. R. Soc. Interface*

2

Constant velocity uniaxial loading and unloading (work-softening)



Pre-conditioned carbon-black reinforced natural rubber specimen



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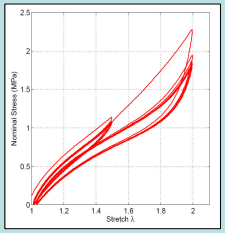
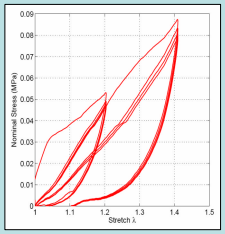
2

Strain specific work softening …….



Pre-conditioned carbon-black reinforced natural rubber specimen

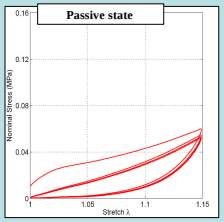


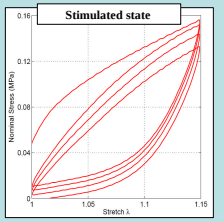
Pre-conditioned *Manduca* muscle (VIL)

From: Dorfmann, A., Trimmer, B. A. and Woods, W. A., Jn. (2006). A constitutive model for muscle properties in a soft bodied arthropod. *J. R. Soc. Interface* in press.

2

Muscle is a multi-state material

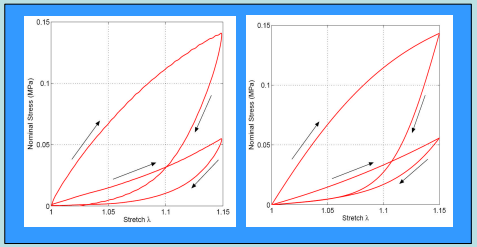




Nerve-muscle preparation

2

Numerical model: *Manduca* muscle



Experimental data (left) and numerical data (right) for pre-conditioned loading-unloading response of *Manduca* muscle in passive and stimulated conditions.

From: Dorfmann, A., Trimmer, B. A. and Woods, W. A., Jn. (2006).
A constitutive model for muscle properties in a soft bodied arthropod. *J. R. Soc. Interface* in press.

2

Soft materials in locomotion

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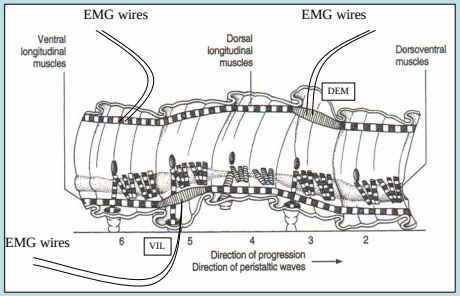
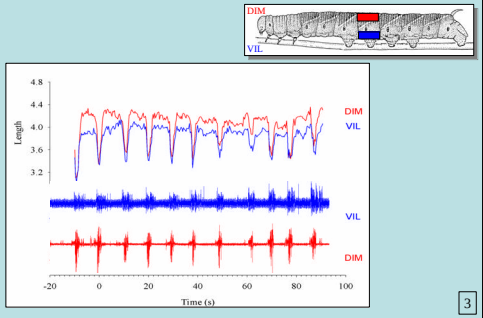
3

Neural control of the crawling motor pattern



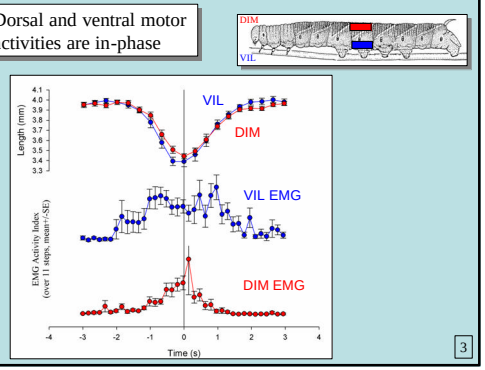
3

Dorsal and ventral muscles co-contract



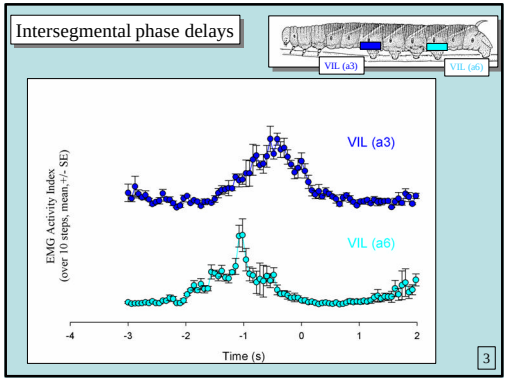
3

Dorsal and ventral motor activities are in-phase



3

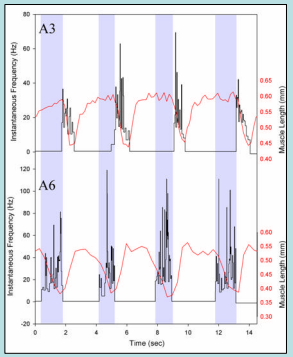
Intersegmental phase delays



3

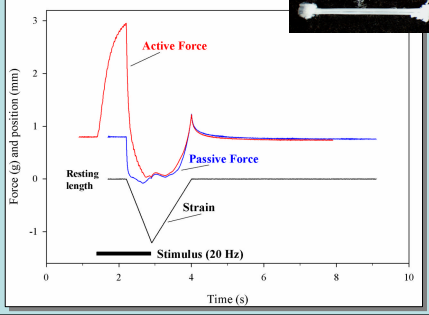
Conversion of the EMG to motor neuron spike frequency

Burst timing relative to muscle length

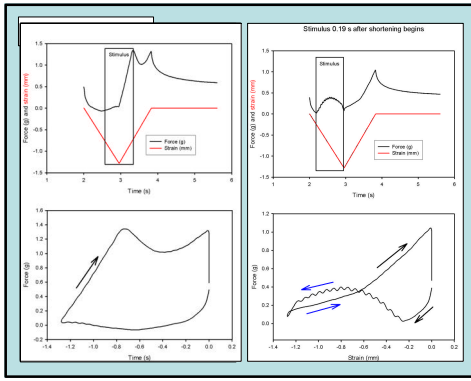


3

"Kinematic" work loop (1)



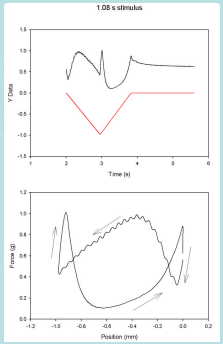
3



3

Stimulus duration

Increasing duration, 20 Hz stimulus



3

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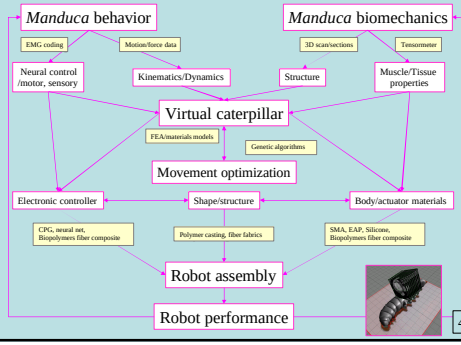
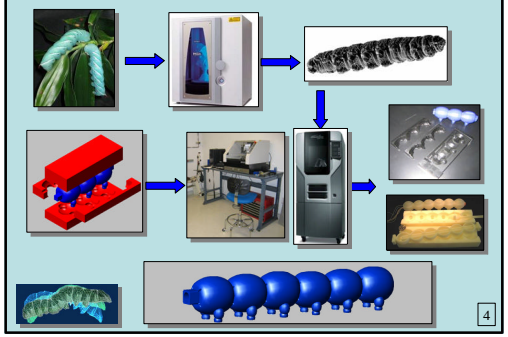
4

Building a soft-bodied robot modeled on *Manduca sexta*



4

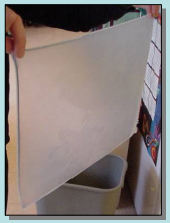
Developing a process

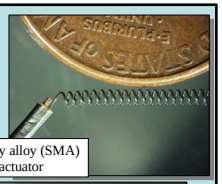


4

Construction of Softbot

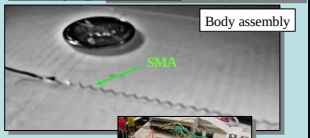
Dragonskin™ elastomeric body wall

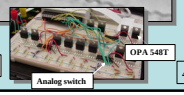




Shape-memory alloy (SMA) spring actuator

Body assembly



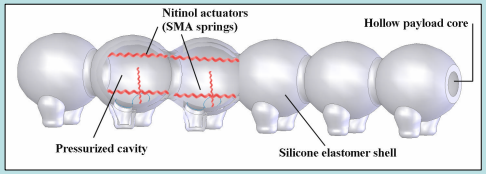


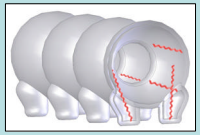
Daniel Rogers - 2005
BREEM summer Fellow

Offboard controller

4

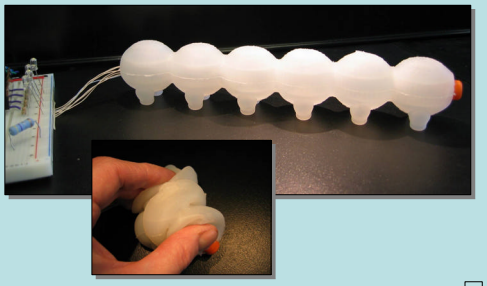
Design of Softbot





4

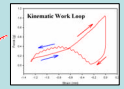
Softbot : Learning to crawl



4

Outline of the control system

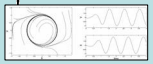
A3 motion



A3 EMG

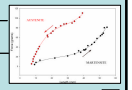
A6 EMG

CPG



Non-linear oscillators
Auke Jan Ijspeert

FM pulses



SMA work cycle

4

Initial control hardware

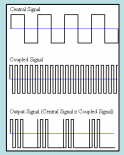
Master Frequency (cadence of crawl)

6 Segments x 12 Actuators oscillator array

Phase Shift, Pulse Duration

On/Off or Invert

Coupled Signal (Pulse duration, duty cycle)

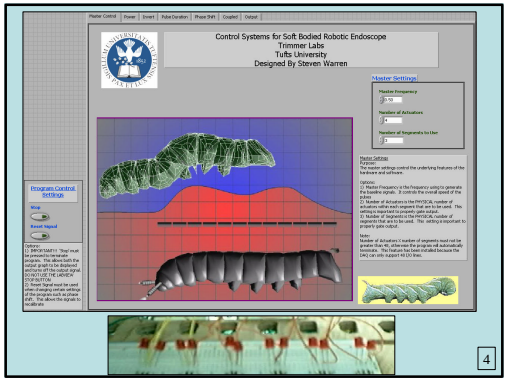


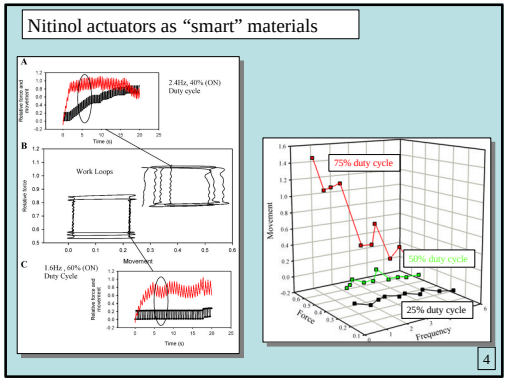
Universal, Segmental or Actuator

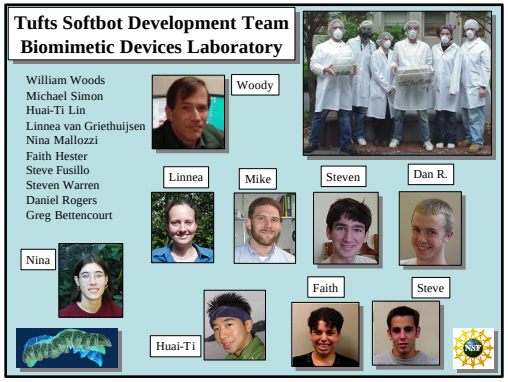
DAQ

Steve Warren (BREEM)

4


Control Systems for Soft Bodied Robotic Endoscope
Trimmer Labs
Tufts University
Designed By Steven Warren
Master Settings
Program Control Settings
4


Nitinol actuators as “smart” materials
2.4Hz, 40% (ON) Duty cycle
Work Loops
1.6Hz , 60% (ON) Duty Cycle
75% duty cycle
50% duty cycle
25% duty cycle
Movement
Force
Frequency
4


Tufts Softbot Development Team
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William Woods
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Nina Mallozzi
Faith Hester
Steve Fusillo
Steven Warren
Daniel Rogers
Greg Bettencourt
Woody
Linnea
Mike
Steven
Dan R.
Nina
Faith
Steve
Huai-Ti
NSF