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On Passive Quadrupedal Bounding with Translational Spinal Joint

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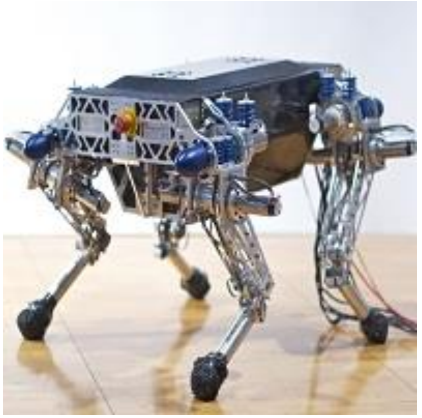
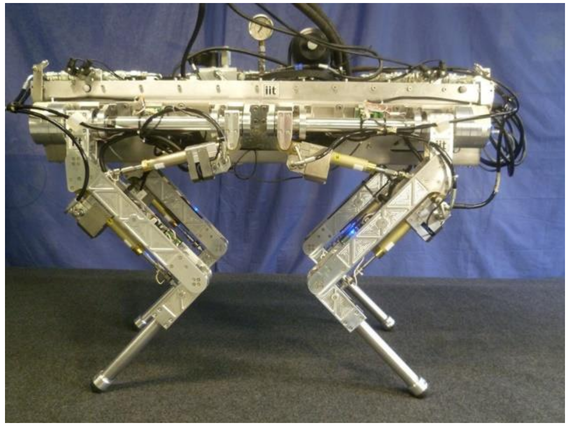
Robotic torso issue

- Rigid torso robots

McGill Scout II

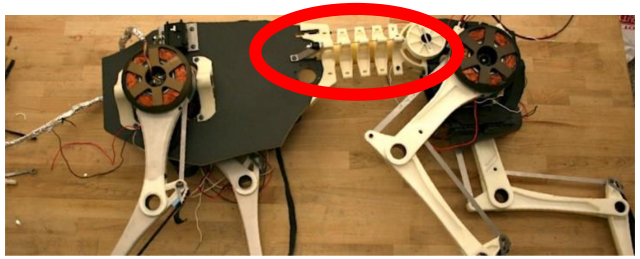


ETH Starleth

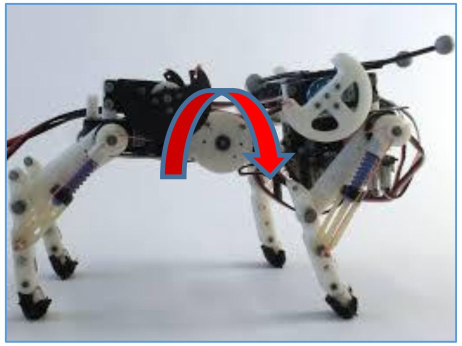


IIT HyQ

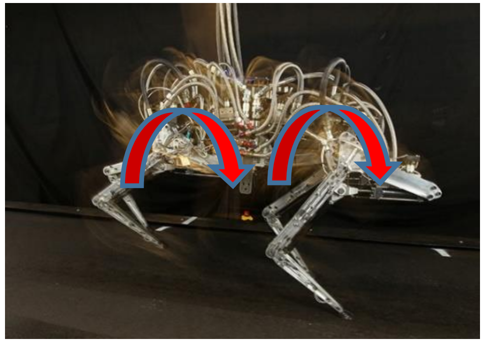
- Flexible torso robots



MIT Cheetah



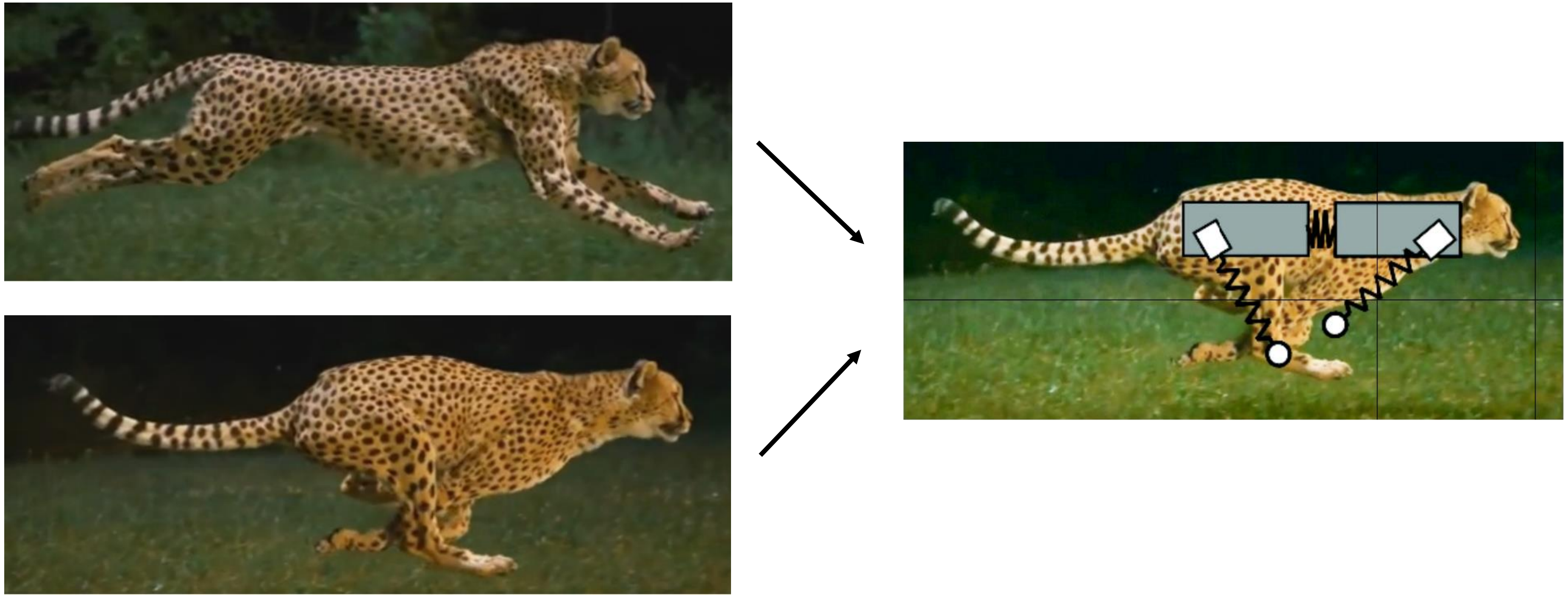
EPFL Bobcat



Boston Dynamics Cheetah

A new approach to spinal joint

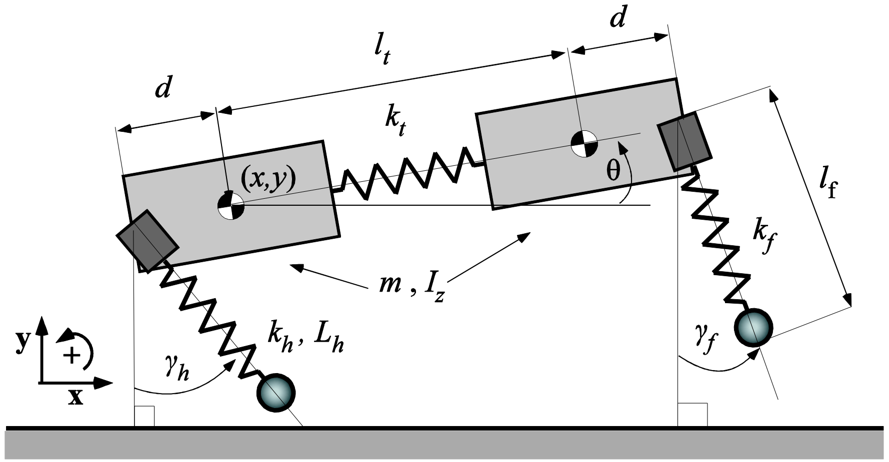
- Robots featuring spinal joints with relatively small range of motion
- Existing robots cannot capture the extensive body length variation



Dynamic model

- Simplified sagittal plane model
- Two identical body segments
- Two massless springy legs - 2 DoF / leg
- Passive spinal translational joint
- Conservative, passive model
- Parameters of real robot (Scout II)
- Lagrangian formulation is used

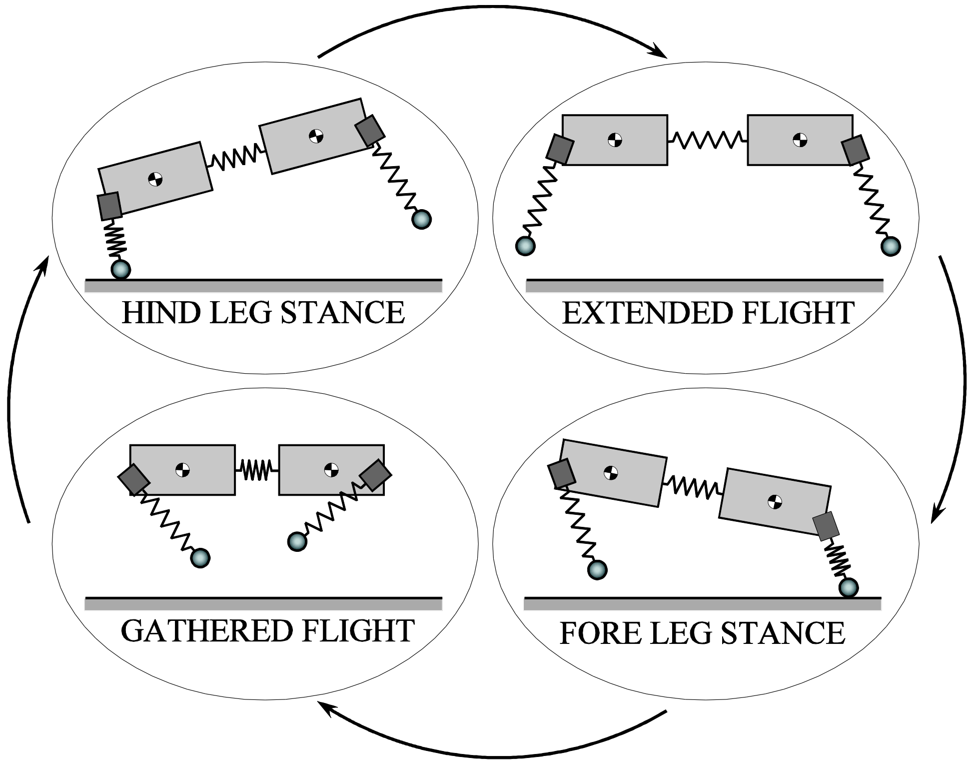
$$\mathbf{z} = (x, y, \theta, l_t)^T$$



PARAMETER	VALUE	UNITS
Fore/Hind Body Mass (m)	10.432	kg
Fore/Hind Body Inertia (I_z)	0.339	kg m^2
Hip to CoM distance (d)	0.138	m
Nominal Leg Length (L)	0.323	m
Leg Spring Constant (k)	7046.0	N/m
Nominal Torso Spring Length (L_t)	0.276	m
Torso Spring Stiffness (k_t)	5077.0	N/m

Gait description

- Animals: gallop for high speed locomotion
- Gallop: asymmetric gait consisting of two flight phases (gathered, extended flight)
- Bound as a limiting case of gallop
- Two aerial – two stance phases
- Leg liftoff and touchdown events trigger phase transition
- No double stance phase

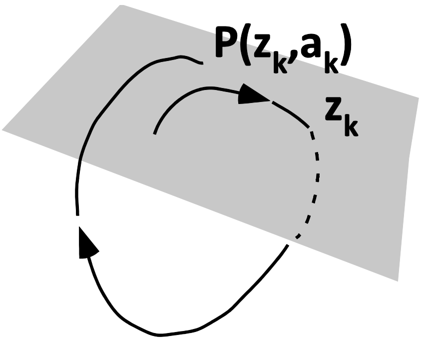


Bounding cyclic motions

- Poincaré return map method employed
- Poincaré section at the spinal joint apex

$$\mathbf{z}[k+1] = \mathbf{P}(\mathbf{z}[k], \mathbf{a}[k])$$

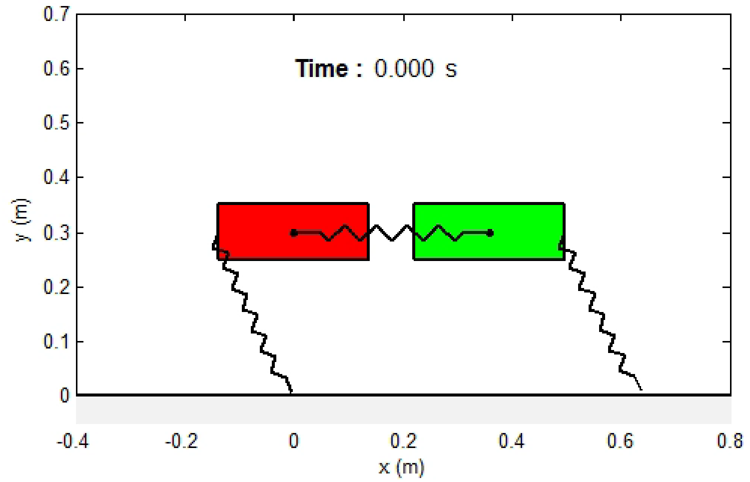
where: $\mathbf{z} = (y, \dot{\theta}, \dot{x}, l_t)^T$ $\mathbf{a} = (\gamma_f, \gamma_h)^T$

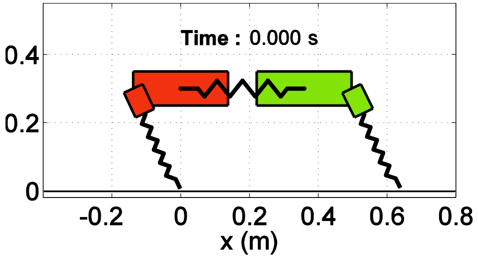


- Fixed points search = find the solution to: $\mathbf{z}[k] - \mathbf{P}(\mathbf{z}[k], \mathbf{a}[k]) = 0$
- Two-level search using MATLAB's *fmincon, patternsearch*
- Result filtering (etc no double stance)

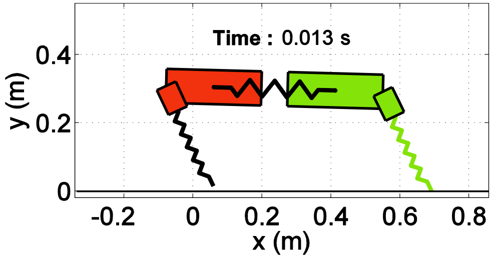
Motion at a representative fixed point

- Gaining insight by studing a representative fixed point

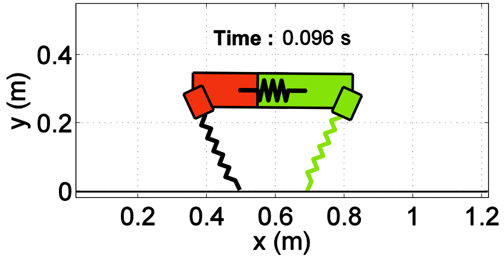




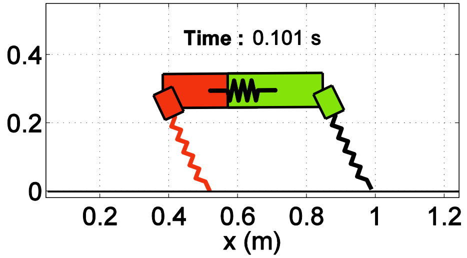
Apex height



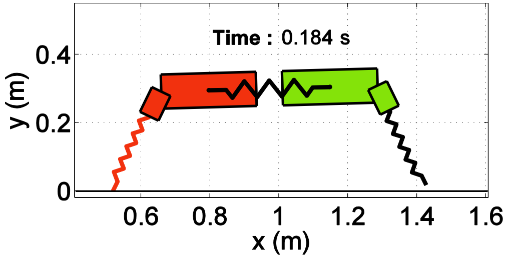
Fore touchdown



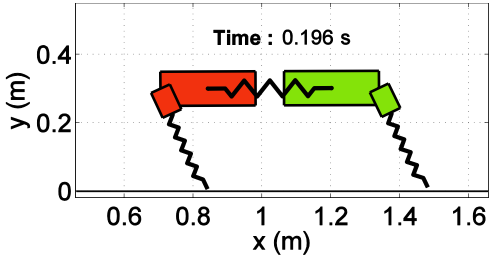
Fore liftoff



Hind touchdown



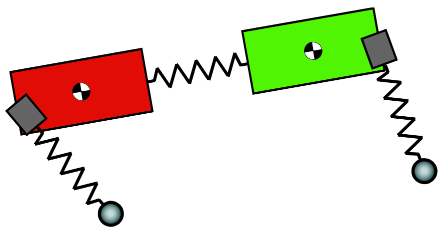
Hind liftoff

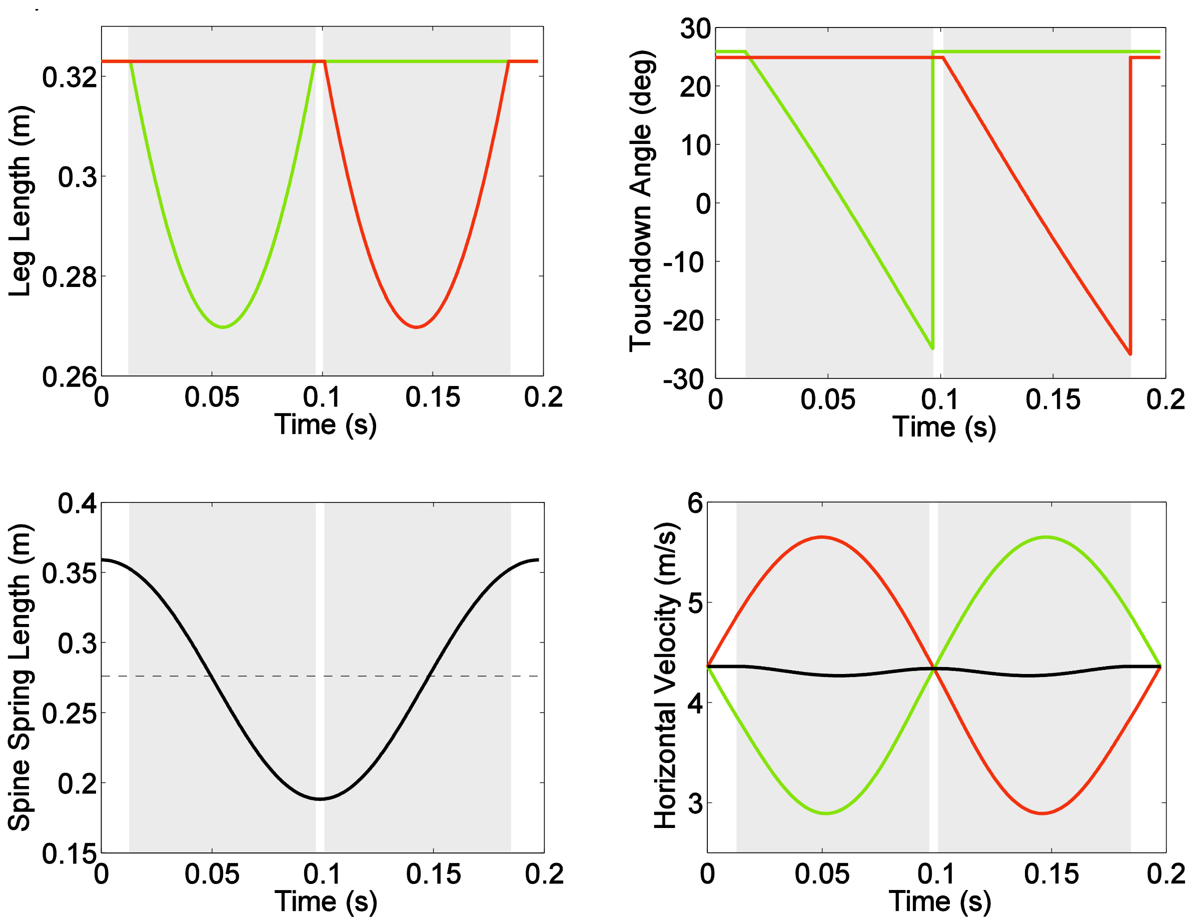


Apex height

Spine contribution to motion

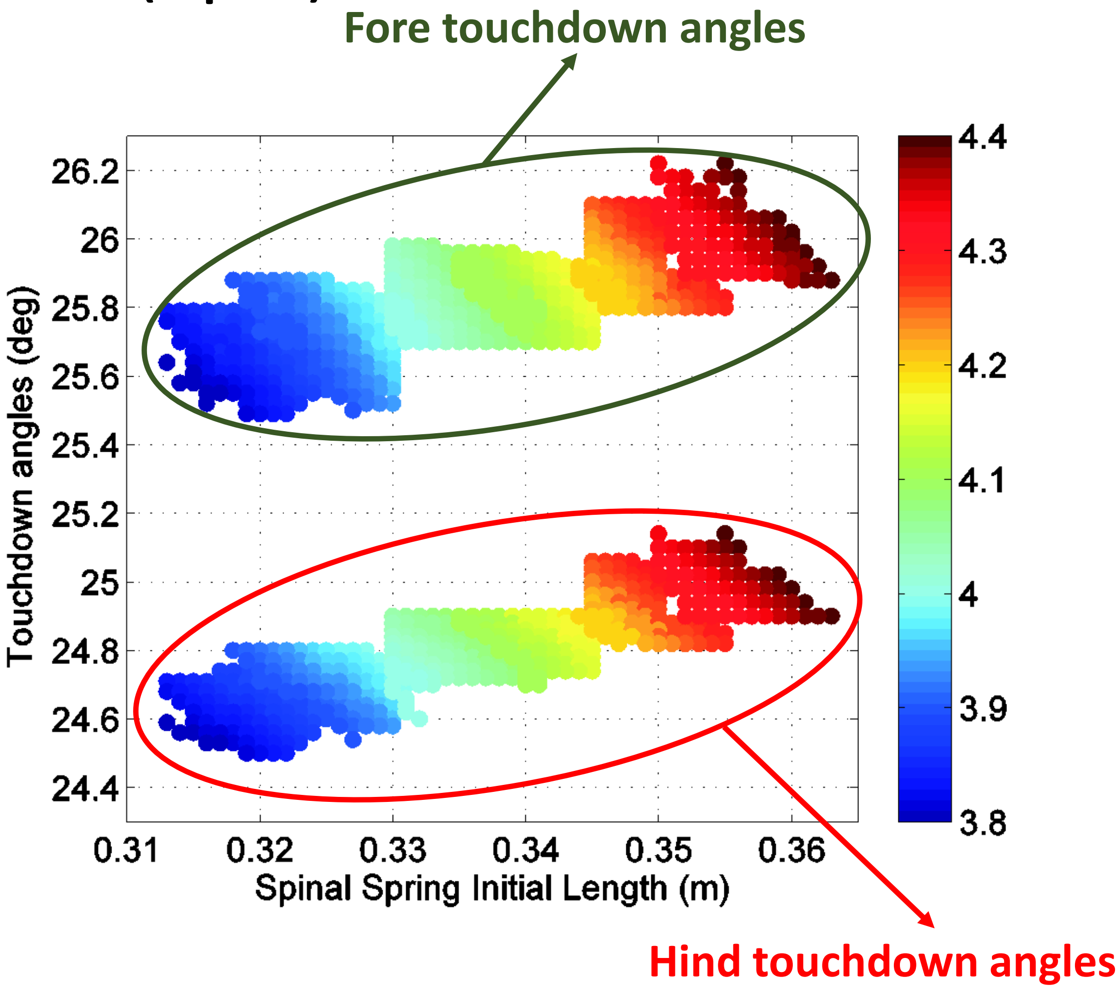
- Symmetry due to periodicity
- Large stance duration
- Extensive bidirectional spine deformation
- Significant horizontal velocity variations for body segments





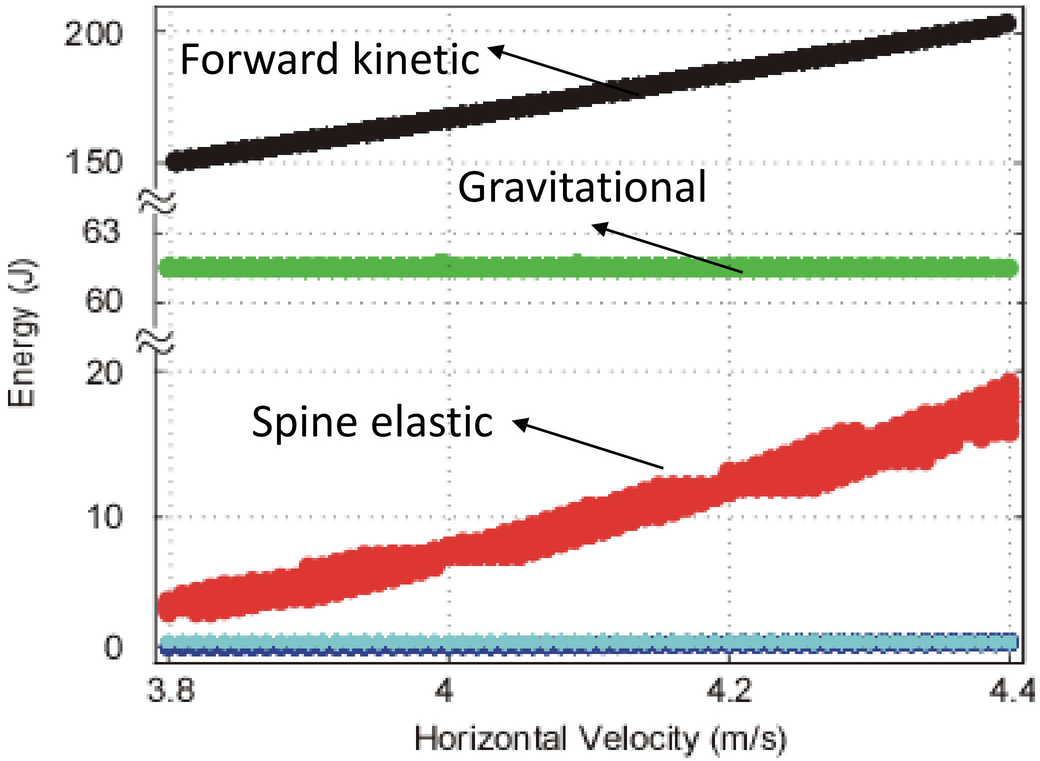
Distribution of fixed points (fps)

- Large amount of calculated fps
- Fps lie in a confined area
- Limited combinations of initial conditions and touchdown angles
- Significant contribution of spine oscillation range to the increase of horizontal velocity



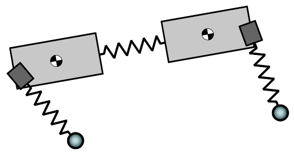
Energy distribution

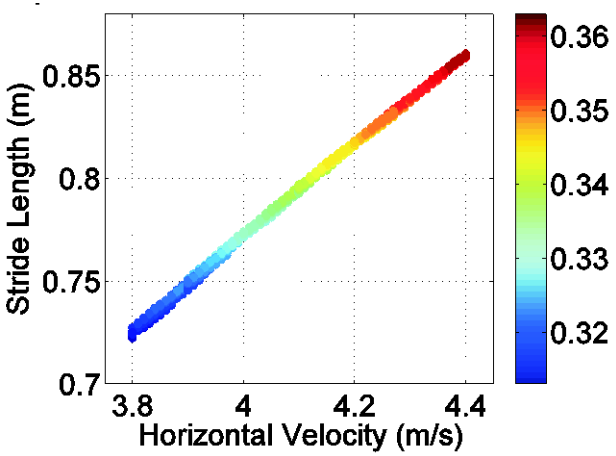
- Spine elastic energy (red line) is closely related to forward kinetic energy (black line)
- Gravitational, rotary and vertical kinetic energy are constant for a wide range of horizontal velocities

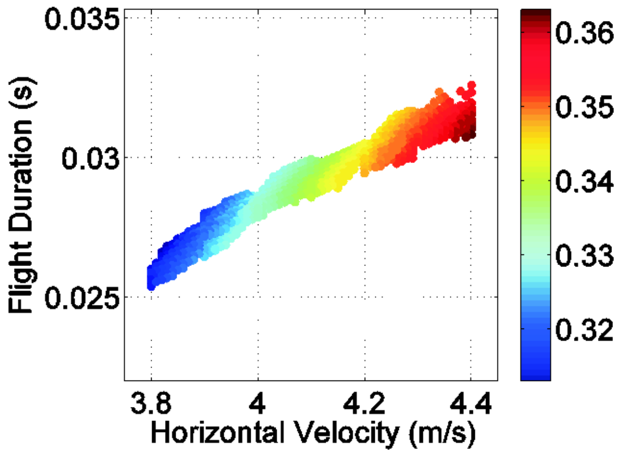


Increasing forward velocity

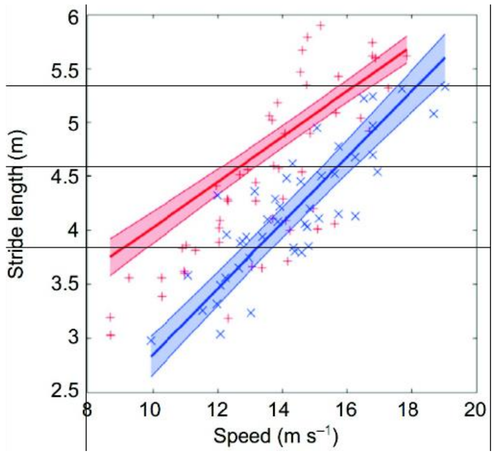
Model performance:

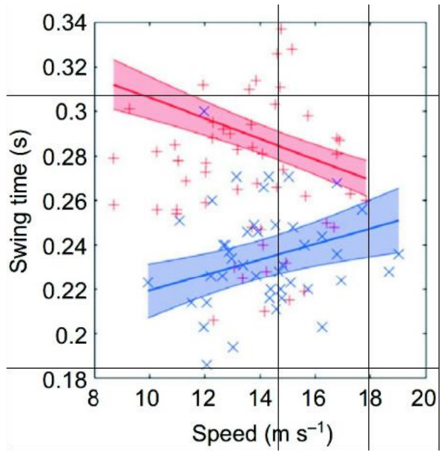




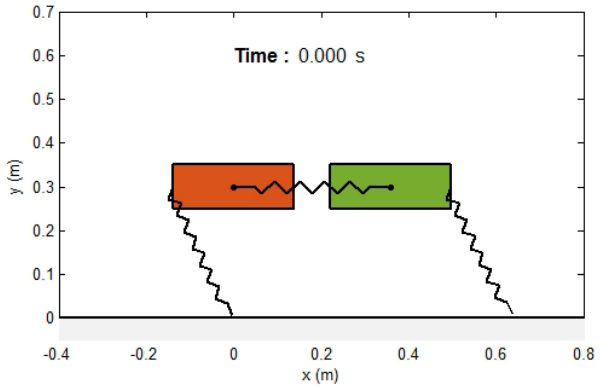


Greyhound performance (blue line):





Conclusion



- <u>New</u> simplified <u>model</u> with translational spinal joint
- <u>Calculation</u> of passive bounding <u>cyclic motions</u>
- <u>Restricted area</u> of fixed points
- <u>Spine</u> is the main mechanism for <u>high speeds</u>
- <u>Model</u> performance <u>resembles animal</u> performance

Acknowledgement

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European Social Fund

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Thank you!

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