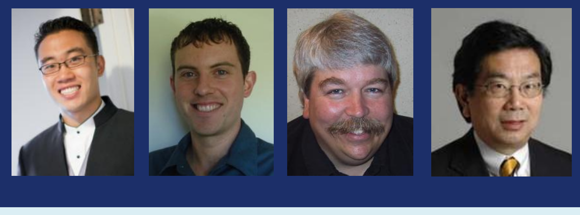
Tailbot – Robot with Inertial Assisted Control by an Active Tail Inspired by Lizards



Evan Chang-Siu[1], Thomas Libby[1], Robert J. Full[2], and Masayoshi Tomizuka[1]

Department of Mechanical Engineering[1] and Department of Integrative Biology[2], University of California, Berkeley

Abstract

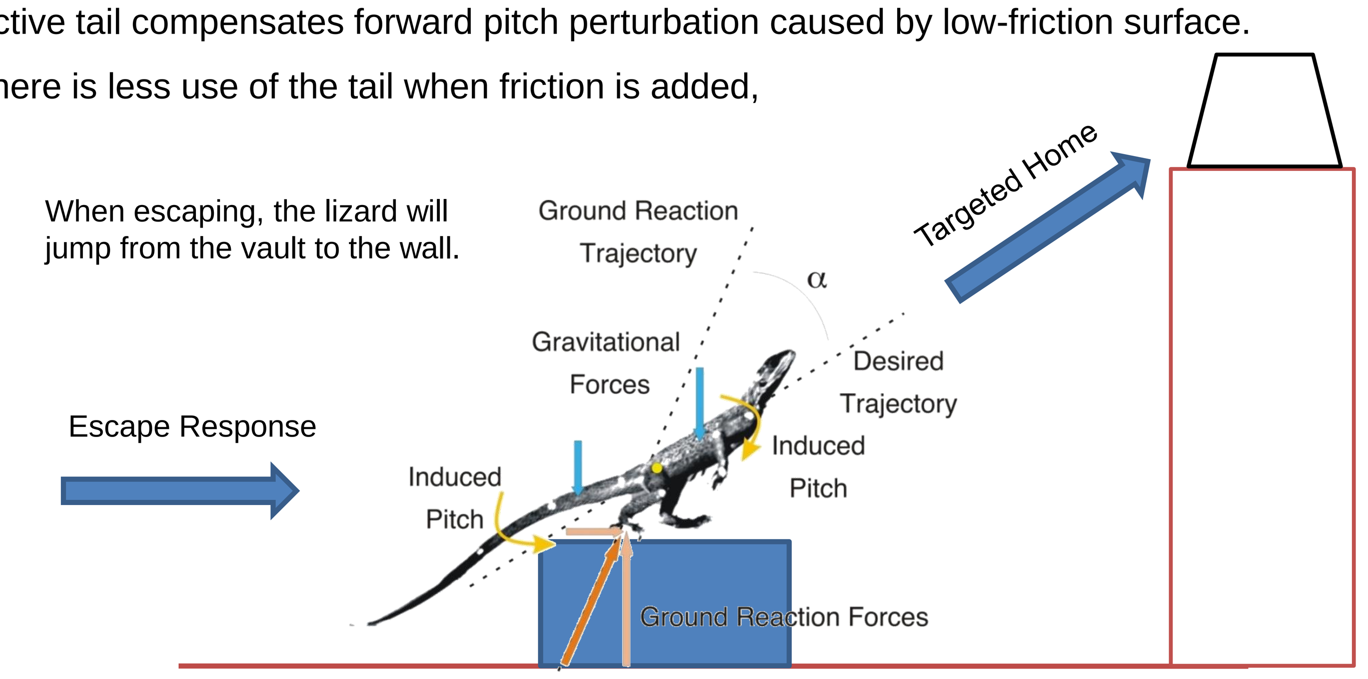
Lizards, discovered to pitch correct in mid-air with their tail when subjected to slippery take-off surfaces, have inspired a novel approach to stabilizing rapid locomotion in mobile terrestrial robots. To demonstrate the benefit and feasibility of this behavior we built a 177 g wheeled robot, *Tailbot*, with inertial sensors, a microprocessor, motor drivers, front wheel drive, and a single degree-of-freedom active tail. Since the relative inertia of the tail is dependent on the squared value of length, the mass of the tail was designed to be less than 20% of the body mass while still allowing for a one to one ratio of relative angular stroke. By estimating the body angle from the inertial sensors and utilizing both contact forces and zero net angular momentum maneuvering, *Tailbot* could take advantage of closed loop feedback control. Feedback produced rapid reorientation during a fall, smooth transitions between surfaces of different slopes, and stability when faced with perturbations that would overturn a tailless robot. Specifically, *Tailbot* could perform a 90 degree self-righting maneuver during free fall in 138 (ms) corresponding to a drop distance of approximately one body length. A perturbation, which completely overturned a tailless robot, produced a 60 degree rotation in a passive tailed robot, but resulted in only a 30 degree rotation in our feedback controlled tailed robot. Landing transitions that were not possible with a tailless robot were made feasible by properly adjusting the reference angle to the tail controller. Capabilities of *Tailbot* demonstrate how an active tail can improve the stability and maneuverability of terrestrial and aerial search-and-rescue vehicles and serve as a physical model to generate new hypotheses of inertial appendage control in animals.

Bio-Inspiration

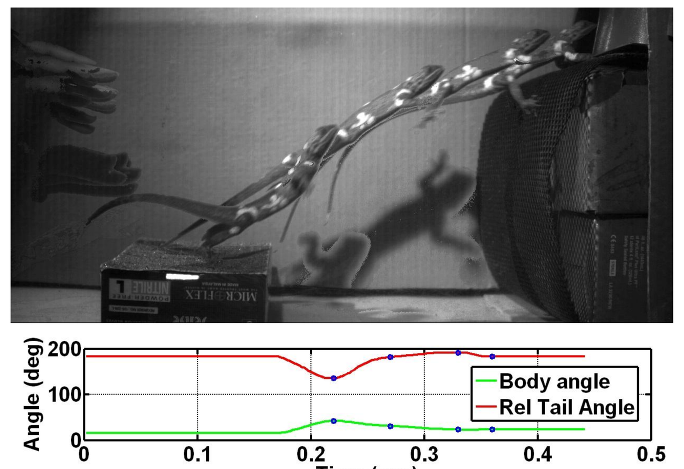
New biological experiment with agama lizards demonstrates inertial use of the tail.

Active tail compensates forward pitch perturbation caused by low-friction surface.

There is less use of the tail when friction is added,

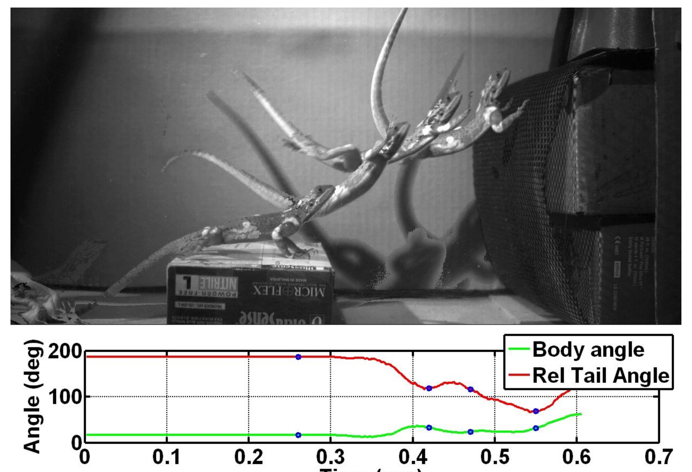


Vault surface friction can be changed.



Friction Vault

Lizard jumps to wall successfully with less use of tail.



Low-Friction Vault

Lizard jumps to wall successfully only by active use of tail.

Acknowledgements

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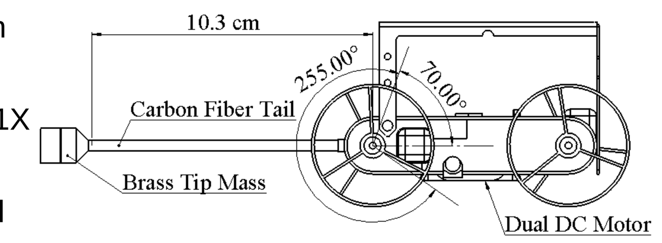
Tailbot

Tailbot is designed take advantage of inertial maneuvers.

Represents a simplified two-link system.

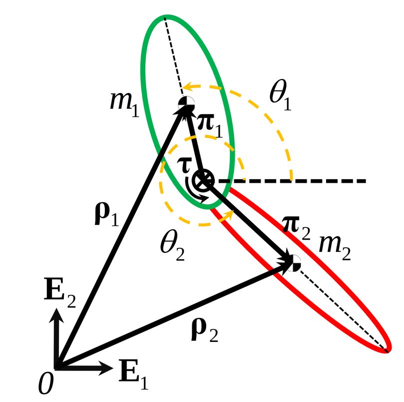
Has the following features:

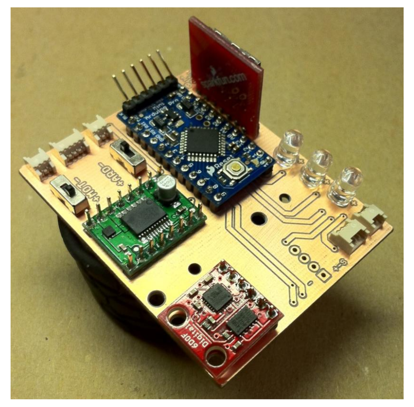
- Tail mass is less than 20% of body mass.
- Tail length is only 1.1X body length.
- Ratio of body and tail stroke is 1:1.



2-Link Model

Model used for design and analysis of tailed system.





Custom Circuit Board

- Arduino 8Mhz microprocessor
- Motor driver
- Inertial Sensors
- LED indicators
- Wireless Communication

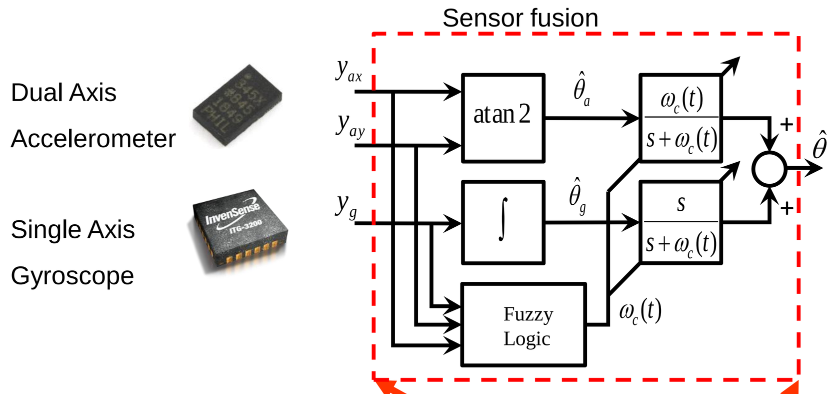
Sensing and Control

An active tail makes it physically possible for feedback control on the body angle.

Intelligently adjusting the body *reference* angle allows T*ailbot* to perform novel motions.

Sensing

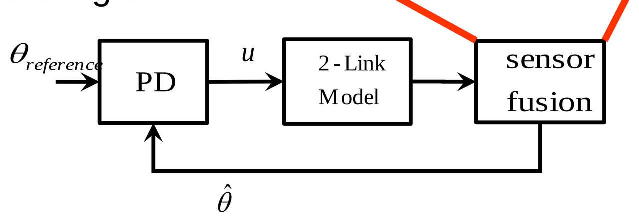
Absolute body angle sensing is achieved through fusing the measurements from a gyroscope and accelerometer with a time varying complementary filter.



Control

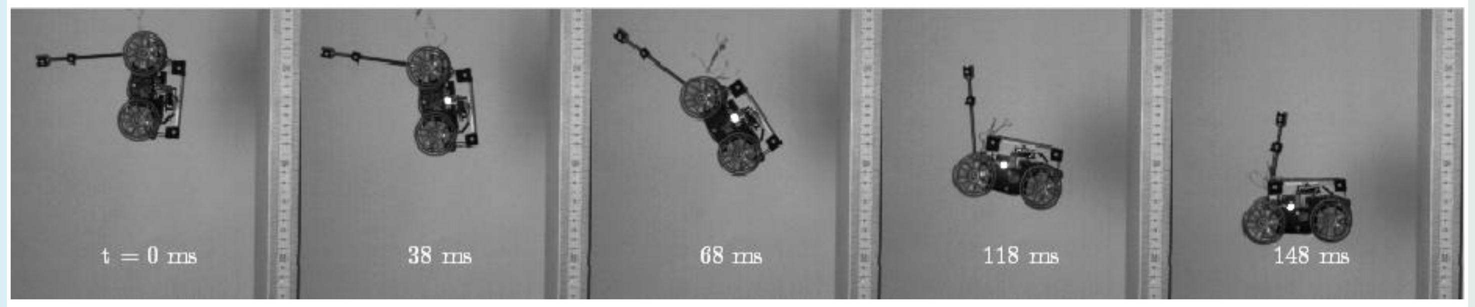
A simple yet effective PD feedback controller on the body angle is sufficient to produce rapid yet controlled maneuvers.

Control Diagram

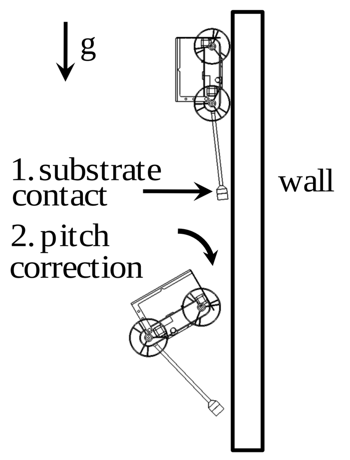


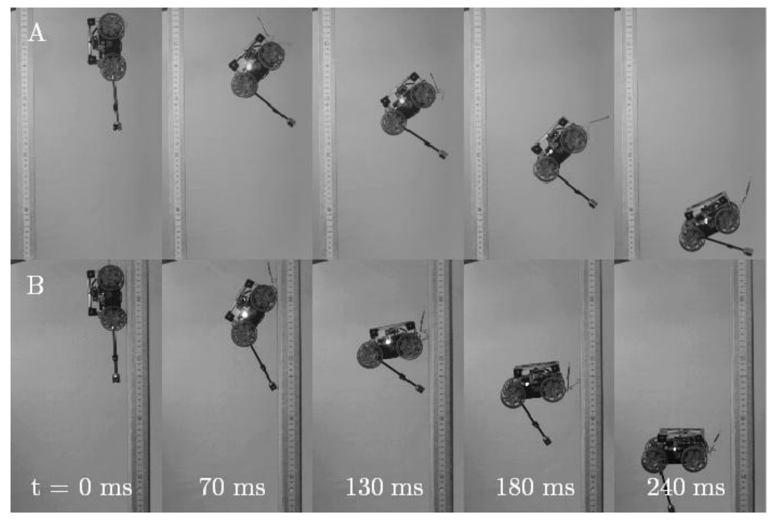
Controlled Fall

When a 90 degree downward angle is detected, the controller swings the tail up to bring the body horizontal. This maneuver is performed in 138 ms.



A tail design will usually have stroke constraints. However, if substrate contact is utilized, angular momentum can be imparted into the system to reduce this constraint, and the robot can still land horizontally.



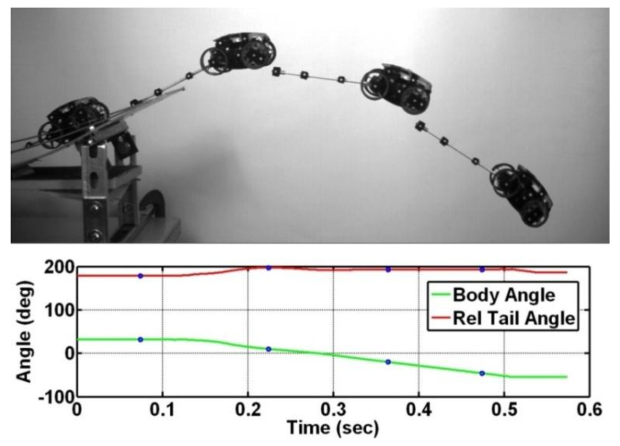


Physical Model

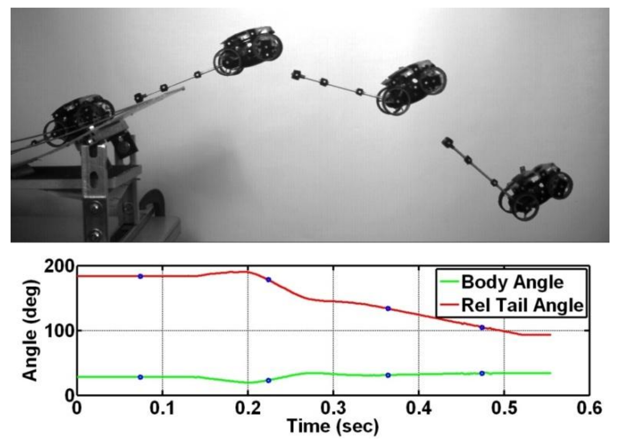
Tailbot served as a physical model to confirm the inertial behavior of the lizard.

This experiment was analogous to the bio-inspiration.

The imbalance of gravity force during takeoff gave the robot a downward perturbation in both cases.



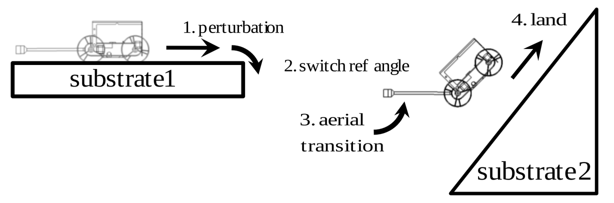
Body angle cannot be maintained with a passive tail.



Body angle can be maintained with feedback control using an active tail.

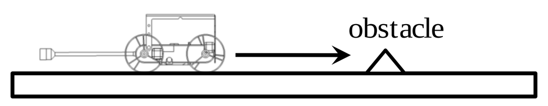
Jumping and Transitioning

With proper choice of body reference angle, an active tail can direct the body angle for a smooth transition to an angled surface.



Perturbation Mitigation

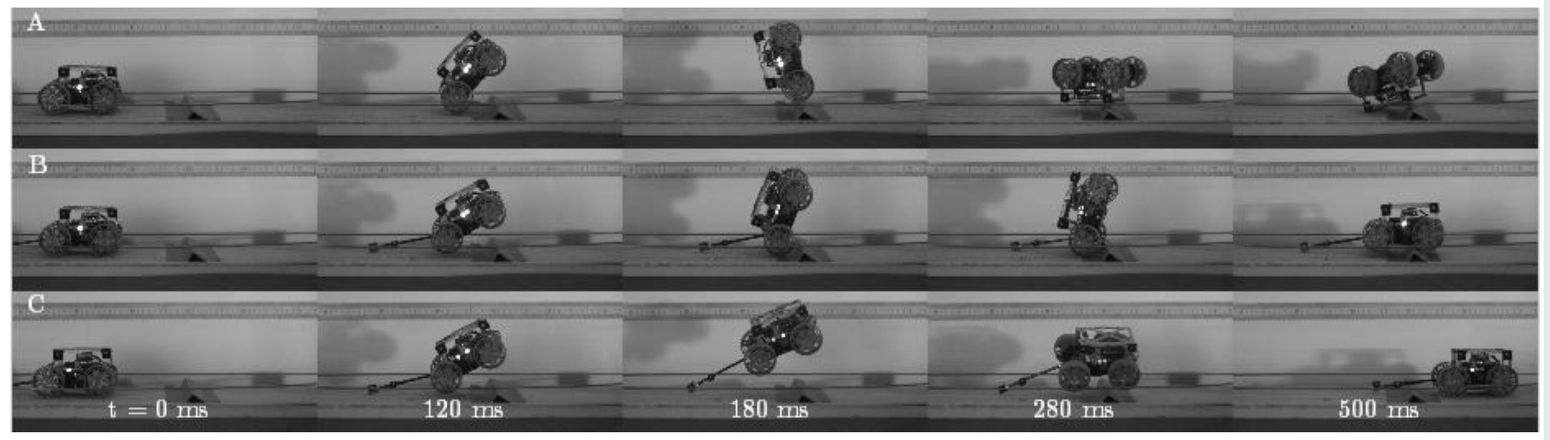
An active tail stabilizes a perturbation the would flip a tailless car.



No tail:
robot catastrophically fails.

Passive tail:
overcomes obstacle with difficulty.

Controlled tail:
easily overcomes obstacle.



Conclusions and Broader Impacts

Traversing unpredictable substrates is still difficult for current robots.

Tailbot can self correct a 90 degree body angle offset in freefall.

With tail design, substrate contact can be utilized to impart angular momentum into system.

Directed body angle makes difficult transitions possible.

Perturbations that would flip a tailless vehicle can be overcome.

In the face of chemical, biological, and nuclear disasters, combining an active tail to the leading mobile robotic designs will lead to faster responding search-and-rescue robots that can help locate and and save more lives.

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