Tail Use in Bioinspired Quadrupedal Locomotion

by

Randall Briggs

Submitted to the
Department of Mechanical Engineering
in Partial Fulfillment of the Requirements for the Degree of
Bachelor of Science in Mechanical Engineering
at the
Massachusetts Institute of Technology

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ABSTRACT

Tails are seen in nature to be used in an amazing number of different applications. Many of these applications seen in nature may be of use to bioinspired roboticists in the future. I have provided a brief review of tail use as seen in nature. An experiment was performed using the MIT Cheetah to investigate the usefulness of tails in one particular instance. The Cheetah was set to stand while a large, standardized disturbance was introduced by means of a clay "wrecking ball." Two cases were observed: one where the tail was actively stationary and another where the tail was swung in order to counteract the disturbance. The actively swung tail was seen to keep the body in the stable region longer than the stationary tail, thus providing the robot additional time to correct for the disturbance with the next foot fall.

Thesis Supervisor: Sangbae Kim
Tile: Edgerton Career Development Assistant Professor

Acknowledgments

I would like to thank Sangok Seok for helping quite a bit with the experimental apparatus setup and for working with me late into the night to get best possible data. I would also like to thank Matt Haberland for a lot of help with comparing tails to existing engineering solutions. I also thank my thesis supervisor, Sangbae Kim, for being particularly understanding during this difficult semester. I had very much difficulty working normally this semester because of a relationship ending in the fall semester. I was very much in love with the girl and was hoping to marry her, so having the relationship end was a major blow. I had intended to do much more work for this thesis, but simply could not.

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1. Introduction

The field of bio-inspired robotics continually mines nature's abundant store of solutions to engineering challenges. However, one aspect of animal motion that has not been thoroughly explored is the incredible variety of ways the tail is used in nature, including balance, swimming, flight control, running, hopping, climbing, defense, warning, courtship, and thermoregulation. Many of these examples could provide engineers with solutions to difficult unsolved problems in robot design.

Only a few robots have incorporated tails for more than aesthetic purposes or as simple fixed inertia. One of the first robots to use an active tail was the Uniroo developed at the Leg Lab. This robot emulated the motion of a hopping kangaroo and actuated the tail to cancel the motion of the leg in order to maintain constant body pitch. Simple robots with tails have been used to reproduce and better understand tail motion in geckos and lizards. These robots demonstrated how tails could be used for orientation control during leaping and falling when no ground reaction is available. Other robots have used swinging appendages to climb stairs and hop. Although these swinging appendages were not referred to as tails, they would fall under the general term of reconfigurable reaction inertia that I would like to introduce. This term encompasses the more diverse manifestations a tail might assume in robotics.

This thesis is meant to be an introduction to the possibilities of tail use in robotics. Its goal is to help with a broader discussion as to which of the uses found in nature might provide solutions for various problems in robotics and how they might be implemented practically. I will begin with a brief overview of some of the notable tail uses found in nature and specifically focus on the cheetahs use of its tail during high speed running. I will then present an experiment meant to demonstrate the usefulness of the tail in one specific example and discuss the experiments implications.

2. Bioinspiration

Biologists have for many years recorded observations of animal tail use. Graham Hickman provided a very entertaining review of these uses in mammals. Kangaroos are known to use their tails both as a counter-balance as they support their weight on two legs and for energy storage during hopping. Dinosaurs are also believed to have used their tails for balance in standing as a gravitational moment. During walking, the tail was believed to swing side to side to maintain the yaw of the body. Long prehensile tails in many species of monkeys are used for balance in climbing and navigating narrow tree branches. These tails are also capable of grabbing onto branches and can allow the monkey to swing with their weight supported. The scaled giant pangolin is capable of rolling into a tight ball while using its large tail as a shield over its body. Many lizard species as well as rodents are capable of intentionally disconnecting their tails in distress to distract potential predators. Pocket gophers are believed to use their bare tails for thermoregulation to help cool their bodies. Lizards and geckos have been observed using their tails in aerial maneuvers to adjust body orientation. Kangaroo rats have been observed swinging their tail in midair to completely turn their body and begin hopping in the opposite direction. Beavers, macropods, pangolins, spider-monkeys, and giant anteaters use their tails as a third leg of a tripod when balancing on their rear legs in order to free their arms for another task such as carrying armloads of mud.

Figure 1 – Two snapshots taken from the BBC's "Life of Mammals" showing the cheetah tail whip from one side to the other during a rapid turn.

Our inspiration to begin this investigation came largely from a video produced by the BBC showing a cheetah during a chase. In this chase, the tail can be seen quickly swinging from side to the other during rapid turns. Figure 1 shows two snapshots from this footage which capture the initial and final position of the tail. We hypothesized that the tail was providing a reaction moment to help roll the body of the cheetah in middair and initiate the turn. The tail can be seen whipping over the cheetah each time a rapid turn is made in this film sequence. We wanted to explore how this might be of use in our cheetah robot and to investigate what other uses the tail might provide for roboticists. However, conventional technologies may also be suitable for providing reaction forces and torques, so first we benchmarked tails against these other technologies.

In order to demonstrate the use of a tail for one purpose in robotics, we designed an experiment based the work of some biologists, which considers tail balance in cats. In their experiment cats were trained to walk along a narrow beam and in random cases a researcher would move the beam laterally a fixed distance while a camera observed the movement of the tail. In every case, the cat would swing the tail in the direction the beam was moved. The researchers then paralyzed the tail muscles of the cat and repeated the experiment, finding that the cats now fell from the beam far more frequently. Walker's work indicated that in situations where the legs could not be used the tail was invaluable to maintain balance.

3. Tail Experiment

3.1. Experimental Setup

In our experiment, the MIT robotic cheetah was set to stand in place while a large disturbance was introduced. In cases when the tail was not activated, the disturbance would tip the cheetah enough to lose balance and fall into the support of the safety cables. With the tail activated, however, the cheetah was able to maintain balance. Figure 2 shows an image of the experimental setup. The tail was driven by a DC motor through a 43:1 gearbox. The mass of the tail was 0.73kg and the moment of inertia about the motor rotation axis was measured to be 0.160kg m2 by the pendulum method.

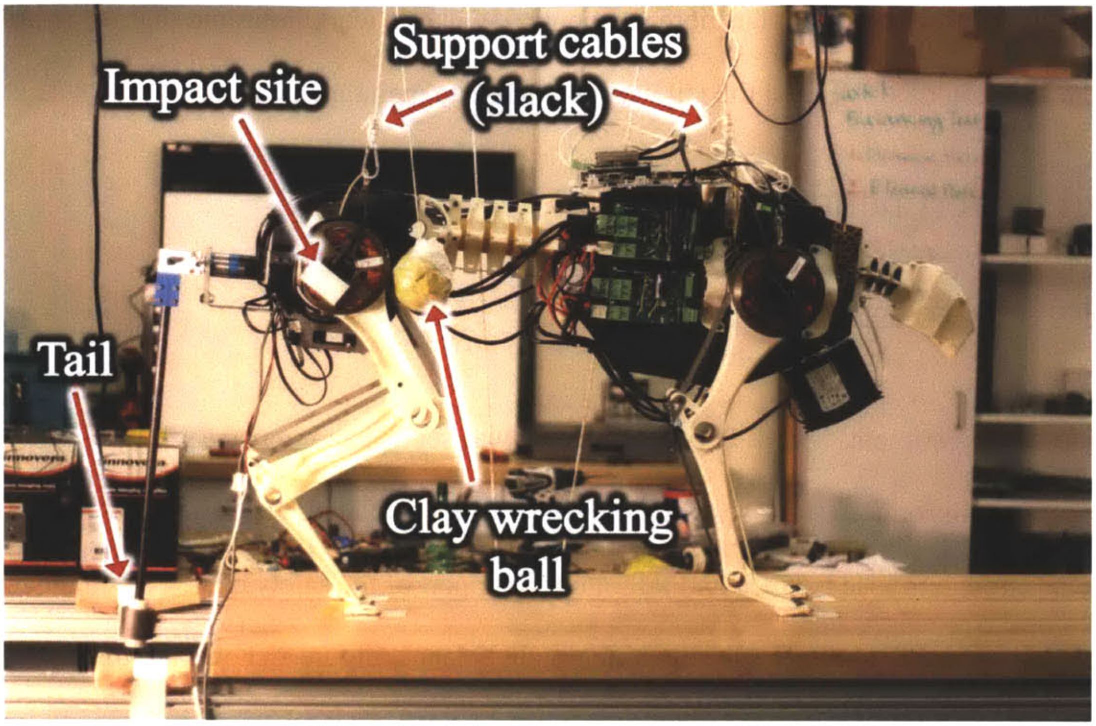

Figure 2 – Experimental setup: the robotic cheetah was set to stand while the clay wrecking ball was swung into the impact site on the rear pelvis. A foam pad was added at the impact site to soften the shock on the robot.

For each trial, the feet of the cheetah were set in the same position as marked by tape on the standing platform. The body orientation was carefully adjusted to ensure the same initial conditions for each test. The servos controlling abduction of the four legs were energized and set to maintain position while the leg length and angle were mechanically locked. To apply a standard disturbance, a clay mass weighing 1.16kg was swung into the cheetah from a prescribed height in each test. Initially, the clay mass was released at different heights to find a level that would consistently knock the cheetah off balance and for all subsequent tests the same height was used. The mass hit the cheetah on the right side of the hip as shown in Figure 5 each time with a velocity of 5 ±0.2m/s. For the active tail cases, the tail was initially set to a slight angle from the vertical toward the incoming clay. In cases where the tail was inactive, the tail was set to this same angle and kept in place with a stiff proportional control. The measured acceleration caused by the impacting clay would start the tail following an open loop trajectory in order to counteract the disturbance and maintain balance of the cheetah. All tests were recorded by a high speed video camera viewing the robot from the rear. Three axes of acceleration, three axes of gyroscope output, motor current and voltage, motor position, and commanded position were all logged in each test.

3.2. Results and Discussion

In all but a few cases, the cheetah would lose balance when struck when the tail was inactive. Reviewing these videos showed the tail initially displaced slightly by the impact only to recover the original position soon after. The momentum of the clay was transferred to the rear hips, which swung outward over the legs until finally causing the cheetah to tip and fall into the support of the safety cables. Movement of the hips was always unidirectional in these cases. Figure 3 shows snapshots of the video taken at different times and Figure 4 shows the horizontal position of the hips as a function of time.

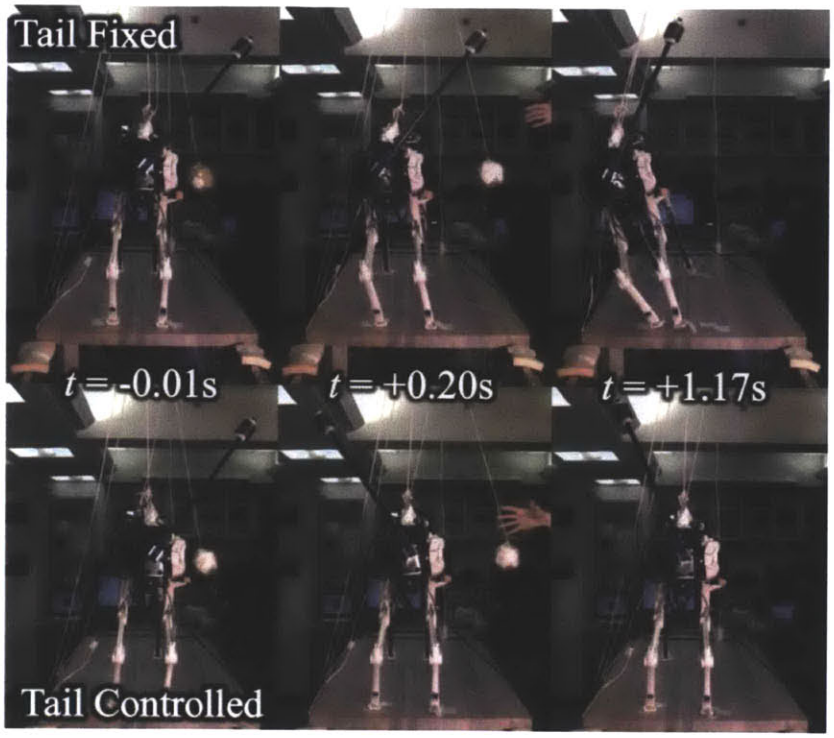

Figure 3 – Snapshots taken from two high speed videos recordings of the experiment. Tail fixed: the tail was set to hold the initial position with a stiff proportional control. Tail controlled: upon impact of the clay wrecking ball, the tail followed an open loop trajectory to stabilize the hips.

Figure 3 also shows snapshots of the case where the tail was activated and followed a set trajectory upon impact. The trajectory was calculated to offset the momentum transfer from the clay and then was manually tuned in several trials. In the case shown, one can see from the plot of hip displacement that the hips initially began to move with the same velocity as in the case with the passive tail. As soon as the tail began to accelerate, however, the hips quickly decelerated and moved slightly back toward the center position. After approximately 0.2s the tail reached the commanded position and began to decelerate thus causing the hips to again accelerate outward. The cheetah did not lose balance, however, and returned to a new, shifted equilibrium in stance. Although this test was performed with the cheetah in a static equilibrium stance phase, the primary purpose was to investigate uses during dynamic walking or running. Our goal was to demonstrate how a tail might quickly react to a disturbance or foot misplacement and keep the body stable until the next foot placement could be appropriately adjusted to be ready for the tail deceleration. In our case, the tail was able to keep the cheetah in the stable region long enough for the legs to apply sufficient lateral ground reaction forces. The additional time allowed these small forces to transfer the momentum needed to keep the cheetah standing.

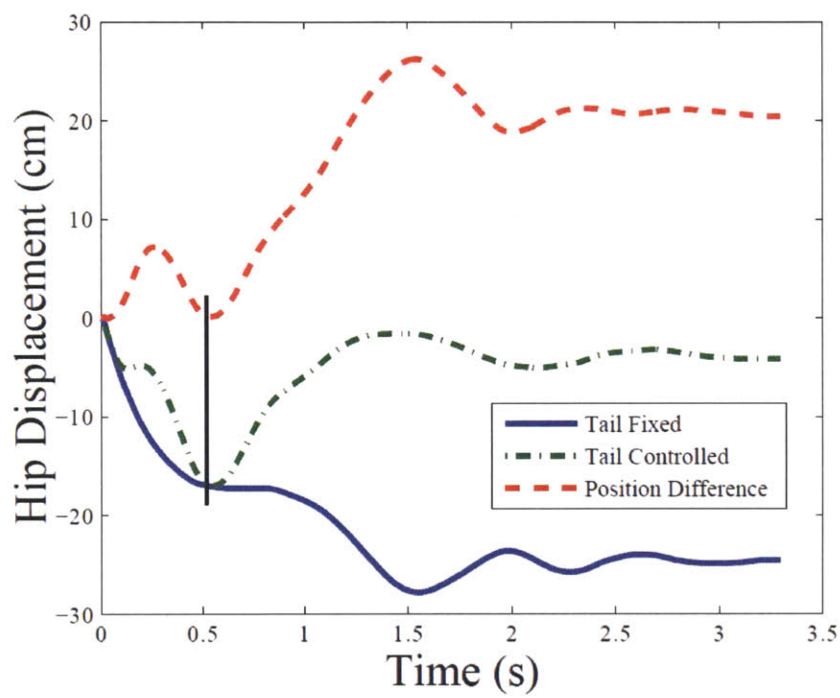

Figure 4 – Horizontal trajectory of the hip for two tests, and the difference between them. Dash-dotted line represents the horizontal position of the hips in the case with the tail actively swinging. Solid line represents the horizontal position of the hips in the case with the tail held fixed. Dashed line represents the difference in position between the two cases. Notice the peak in the difference created by the motion of the swinging tail. The swinging tail allows for more time in the stable region when a correcting foot placement can be made. The region to left of the dividing bar is very consistent between all the experiments, whereas some variation is seen to the right.

Our focus was to produce the motion that can be seen in Figure 4 before the black dividing bar. This portion of the plot had almost no variability in each trial for both the inactive and active cases. The tails primary function is to delay the motion of the body induced by the clay. The plot of position difference shows a significant peak at about 0.23s where the inactive tail case has progressed about 7cm beyond the active tail case. This difference in many instances can be crucial in maintaining stability long enough for the next stride to be planned appropriately.

4. Conclusion and Future Work

The breadth of tail use found in nature is truly incredible. It seems that there will be a number of opportunities for researchers to incorporate tails in the design of future robotic quadrupeds for various purposes but especially for use in balancing and momentum correction. My work was focused on demonstrating one particular instance where having an active tail could mean the difference between a slight misstep and falling over completely. The results demonstrated that the tail was clearly allowing for extra time near the stable, home position during which time computation on board might direct the robot to correct for the disturbance with the next footfall.

I had hoped to spend quite a bit of time on the design of the final tail, but unfortunately was not able to. A final design would likely use cable actuation with electric servomotors. The tail could have a core that is stiff in compression but flexible in bending such as NiTiNol. The cables would be guided by multiple segments behaving much like vertebrae. It seems that only two degrees of freedom would be necessary to cover the space of interest for tail movement, although more DOF's may be preferable to avoid any singularities present. The home position of the tail would have to be changing constantly to avoid the ground as the pelvis makes drastic movements. One interesting idea would be to have the tail stiffness be tunable such that it could be very stiff during acceleration, providing a sharp impulse, and then quite flexible during deceleration, thus spreading out over time the momentum transfer necessary to stop the tails movement.

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Appendix A

Lab Notebook

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1-20-12

I returned to campus a couple of days ago and have begun working on the tail of the Cheetah once again. It sounds like the tail will become important fairly soon, so Sangbae wants work to be done quickly for the development and testing of the tail concept and then fabrication and implementation of the final design. I will be working on some simple calculations of the tail dynamics and then performing an experiment with a force/torque sensor to see how a whipping rod-like tail actually behaves. This can be compared with the results from a computer simulation.

TO DO

- very simple, first order calculations
- write down list of desired data and results from simple tail experiment
- Design experiment and simulation to achieve these goals.
- Spend some time reviewing the papers on tails and watching the cheetah videos and write down some hypothesis of tail function and functional requirements for the robot's tail
- Talk with Sangbae about the scope of the paper and figure out further plans

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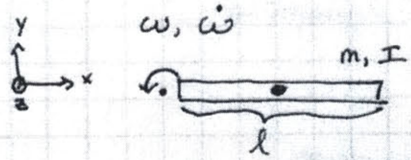
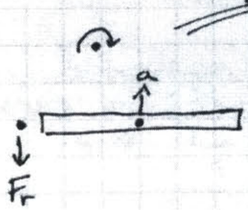
1-23-12



$\tau = I\dot{\omega}$ torque on rod

reaction torque $\tau_r = -I\dot{\omega}\,\hat{z}$



$F = m\vec{a}$

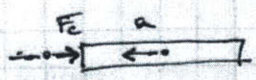
radians = arc length / radius

radius · angular velocity (rad/s) = $\frac{\text{arc length}}{\text{sec}}$ $\approx$ linear velocity

$$a = \left(\frac{\ell}{2}\right)\dot{\omega}$$

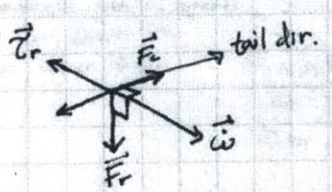
$$\cancel{F_r = -\frac{\ell}{2}\dot{\omega}\,\hat{y}} \quad F_r = -m\frac{\ell}{2}\dot{\omega}\,\hat{y}$$

Centripedal acceleration



$$a = \frac{v^2}{R} = \frac{(R\omega)^2}{R} = \omega^2 R = \omega^2\frac{\ell}{2}$$

$$F_c = m\omega^2\frac{\ell}{2}\,\hat{x}$$

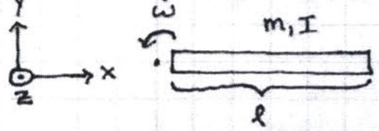


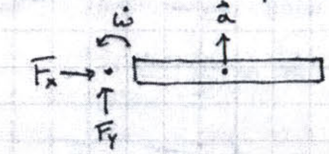
1-23-12

Some simple calculations for the dynamics of a rod-like tail

Conservation of Linear Momentum

Assume a thin, rigid rod is accelerated with angular velocity, $\dot{\omega}$, about one of its ends. what is the resultant torque and force experienced at the pivot point?





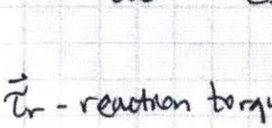
$\Sigma F = m\vec{a}$ $\qquad$ $\vec{a}$ is acceleration of center of mass

$$\vec{a} = R\dot{\omega} = \frac{\ell}{2}\dot{\omega}$$

$F_x = 0$ since $\vec{a}_x = 0$ $\qquad$ $\boxed{F_y = -\frac{m\ell}{2}\dot{\omega}}$ $\qquad$ F_y is in the negative y direction since it is the force applied by the rod to the base.

Conseration of Angular Momentum

to simplify the formulation, the point used for reference will be the ~~center of mass.~~ pivot point at end.



change in ang. momentum about CM

change in ang. momentum of mass as a point mass at CM

$$\Sigma\tau = \frac{d\vec{L}}{dt} = I_{cm}\dot{\omega} + \frac{d(\vec{R}\times\vec{p})}{dt}$$

$\vec{\tau}_a$ - applied torque

$$= I_{cm}\dot{\omega} + \frac{\ell}{2}\cdot m\dot{\vec{v}}$$

I_{cm} - moment of inertia about CM

$$= I_{cm}\dot{\omega} + \frac{\ell}{2}\cdot m\frac{\ell}{2}\dot{\omega}$$

$$= \left(I_{cm} + \frac{m\ell^2}{4}\right)\dot{\omega}$$

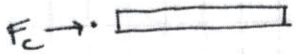
$\vec{\tau}_r$ - reaction torque

$$\boxed{\vec{\tau}_r = -\left(I_{cm} + \frac{m\ell^2}{4}\right)\dot{\omega}\,\hat{z}}$$

$$I_{cm} = \frac{m\ell^2}{12}$$

1-23-12

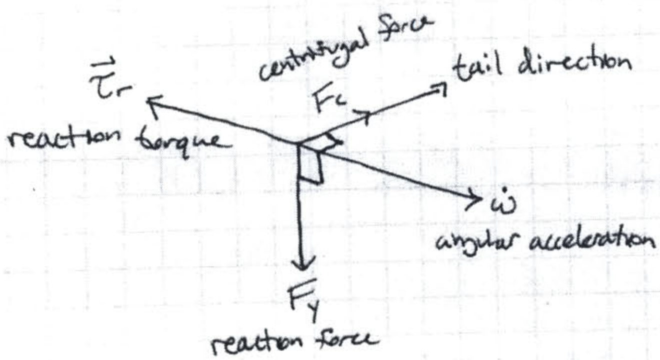
Centrifugal force



$$F_c = ma = m\omega^2 r$$

$$\boxed{F_c = \frac{ml}{2}\omega^2}$$

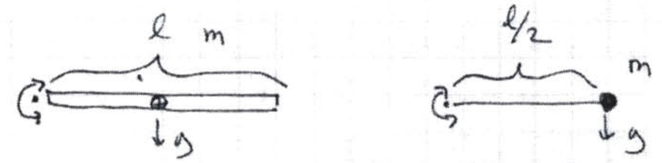
As the tail starts to build up speed, ~~It~~ the body will begin to be affected by the centrifugal force of the rotating tail.



The diagram on the left shows how the directions of these various components are related in free space.

Above, the tail direction is perpendicular to the angular acceleration. This will most likely be the case for our simple tests, but will not necessarily be true for the general motions of the tail.

1-26-12



same holding torque $\tau = \vec{F} \times \vec{r} = mg\frac{l}{2}$

but not the same moment of inertia

$I = \frac{ml^2}{3}$ $I = m\left(\frac{l}{2}\right)^2 = \frac{ml^2}{4}$

So, less dense and longer rods have a higher moment of inertia to holding torque ratio

However, for a fixed length, moment of inertia is maximized for a given mass by concentrating all of the mass at the end. This may prove useful if we need a shorter tail in order to avoid interference with the ground.

So, Sangbae has mentioned that we are hoping for a tail that can dissipate the angular momentum more smoothly than a rigid rod would. It seems like something with a variable or rather controllable stiffness would be useful. I'll have to look into different ways of achieving this.

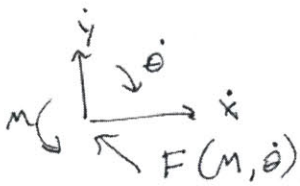
1-30-12

Plan for experimental setup

Monday
order circuit components
F/T connector is all set
read last part of nature tail paper
read gecko tail paper

Compensate coupled angular disturbance

2-2-12



solve for power

$$P(\dot{x}, \dot{y}, \theta, \dot{\theta}, M)$$

$$\min P(\dot{x}, \dot{y}, \theta, \dot{\theta}, M)$$

$$P = \underset{\sim}{v} \cdot \underset{\sim}{F}(\tau, \overset{\theta}{\omega}) + \underset{\sim}{\omega} \cdot \underset{\sim}{\tau}$$

xe

2-8-12

Future work - interested in using tail to get hind legs to some angular position during flight.

standing one

IROS

3D simulation of 2 body flight phase control of angular state for fixed time

Specific gait IC's

body has small $\underset{\sim}{\omega}$ and $\Delta Q \rightarrow \underset{\sim}{0}$

Don't care about final state of tail in short time (~100-200 ms)

so maybe we only care about Q (tend)

maybe $\underset{\sim}{\omega}$ doesn't matter

we propose that we can use a tail as a massive appendage for the sake of state regulation. We have a few possibilities shown and we would like to propose other possibilities

Coupling - show that tail is not just used in one plane but can be used to affect orientation in 3D.

Experiment - standing on all fours

Decreasing settling time after disturbance

Sim - inverted double pendulum

Someway of controlling exact impulse so that we can just barely knock cheetah off balance and then use same impulse to try again but stabilize with tail.

rotating/moving rear legs to different landing position.

simplify 3D problem of standing because tail is much lighter than body and tail is moving much faster than body

force source? torque source?

tail vs. reaction wheel

reaction wheel can do clean torque with continuous motion

compare torque and angular momentum transfer

long tail can provide more torque for more time versus a small reaction wheel that would start to speed up and we would lose our maximum torque.

we are working with short time scales where perhaps it is better to have a device with a large moment of inertia that can be accelerated during flight without speeding up too much.

perhaps reduce stiffness of legs until the standing is unstable and then use tail to stabalize (andres mentioned this ~~formulation~~ phenomenon)

Plan for cheetah standing experiment

we will use the maxon motor in lab

The speed is 391°/sec, which is 30% faster than the dynamixel AX-12

We will use a carbon fiber rod 0.5" diameter 3ft long with two shaft collars to hold on our iron weight. Perhaps we should use nylon shaft collars to minimize their mass.

I will design an aluminum attachment or coupling rather that will hold the ~~aluminum~~ carbon fiber rod and mount to the motor shaft. It would be nice to put some way of indicating angle on this device. Perhaps I can incorporate a protractor.

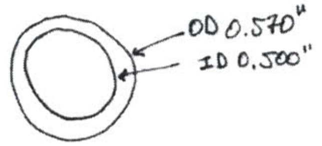
I will design an aluminum mounting plate to attach the motor to the top of the cheetah's pelvis.

Do calculation for carbon fiber stress level and weight

Do calculation for size of iron weight and it's moment of inertias

2-12-12

Carbon fiber tube



Cheetah tail from Alan Wilson's paper

mean mass - 0.66 Kg 2% of body mass (± 0.08 Kg)
Moment of inertia - 0.018 Kg m^2 at center of mass (± 0.004 Kg m^2)
tail length - 750 mm (± 20 mm)
com located 188 mm from base of tail

$$I \text{ at tail base} = (0.018\ \mathrm{Kg\,m^2}) + (0.66\ \mathrm{Kg})(0.188\ \mathrm{m})^2$$
$$= 0.0413\ \mathrm{Kg\,m^2}$$

For our carbon fiber rod of Length 3 ft, this is equivalent to about 40 g at the end

If we make our tail 2 ft long, we will need a mass of approximately 110 g to keep the same moment of inertia

Iron density 7.87×10^3 Kg/m^3
actual 7.2×10^3 Kg/m^3 (from McMaster)

$$\pi R^2 \cdot l \cdot \rho = m \qquad R = 1\text{ in} \quad l = ? \quad \rho = 7200\ \mathrm{Kg/m^3}$$
$$m = 100\text{ g}$$
$$l = \frac{m}{\pi R^2 \rho}$$
$$l = 0.27\text{ in}$$

so we need very little iron to obtain the mass that we're looking for.

2-12-12

ok, so let's say we're at 10 times this moment of Inertia and we're accelerating to the full speed of the motor in 0.1s. Will this cause too much stress in the carbon fiber rod ?

$$\tau = I\alpha$$
$$= 10\,(0.04\ \mathrm{Kg\,m^2})\,(391°/s)\,(0.1s)^{-1}$$
$$\tau = 27.3\ Nm$$

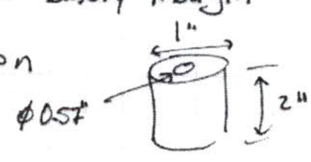
$$\sigma = \frac{\tau}{J_{xx}} y \qquad \tau = 27.3\ Nm$$

$$J_{xx} = \frac{\pi}{4}\left(r_2^4 - r_1^4\right) = \frac{\pi}{4}\left(\left(\frac{0.57}{2}in\right)^4 - (0.25)^4\right)$$
$$= 9\times10^{-10}\ m^4$$

$$\sigma = \frac{27.3Nm}{9\times10^{-10}m^4}\left(\frac{0.57in}{2}\right) = 220\ MPa$$
$$= \boxed{33{,}000\ psi}$$

For carbon fiber, tensile strength is 120,000 - 175,000 psi so we are well within the safety margin

quick check of mass of iron



= 125g

If the OD is 2"

= 681 g

→ Let's buy the 2" rod

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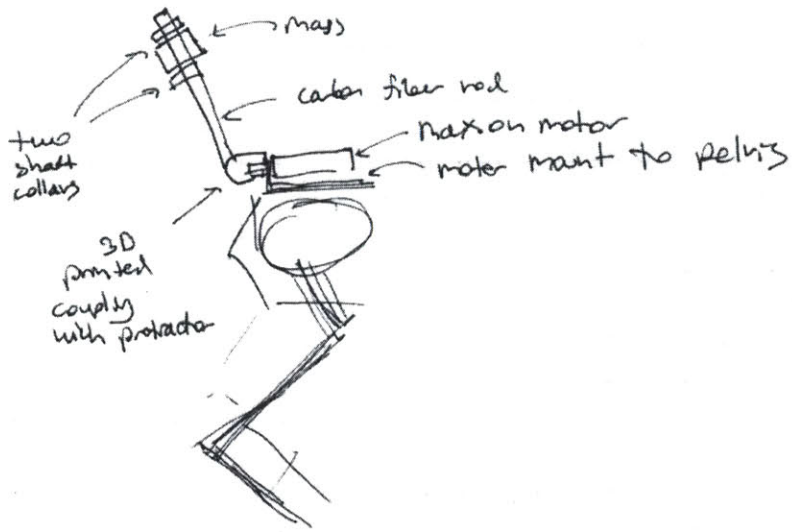
2-12-12



I don't think I feel comfortable with the entire coupling being 3D printed. I don't know, perhaps it would be fine.

Tensile strength of ABS - 63.4 MPa

torsional stress in shaft ~~≈~~ 162 MPa at 27 Nm

let's try $\frac{27}{2}$ Nm : torsional stress : 80.19 MPa

Maxon motor info

Encoder : MR pg. 239 225787?

Gearhead : 203126 113:1

Motor : RE 40, but don't know which model
pg. 83

2-15-12

Tail Meeting

Jong Woo has finished equations of motion

test control algorithms used in previous work ~~on our~~ for our body
PD control and computed torque control

tail is helping place legs at a certain angle that might not be possible otherwise

A we are observing tail canceling forces and torques from other appendages.

talk about putting tail in preparatory position slowly and then swinging it quickly

Federer forearm with twisting lower body to cancel torque of upper body

ask matt

tail vs. flywheel for short time limitation

the two will prefer different gear ratios

optimum gear ratio for angular momentum in a certain time

Tail Paper Ideas

Tail vs. Reaction wheel

3D simulation of 2 body entity with angular position control of body

control during fixed time interval

final position of body matters, but final position and velocity of tail is not important except for avoiding ground contact

Maybe tail is not that useful when thinking of the whole body, but quite useful when you think of just offsetting the disturbance from one other appendage

We could do simulations with this kind of phenomenon in mind where we include in the model another appendage with ~~that~~ properties similar to the real cheetah legs

The standing test will definitely still be useful and informative and will be a nice demonstration of tail use in the real world

One big advantage of tail over reaction wheel is that the tail can be used in multiple ways or connections, ie multiple torque and forces directions, whereas a reaction wheel is only good for one axis and only for torque.

"Reconfigurable Reaction Wheel"

For Murata boy and girl site the official website

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2-20-12

Tail offset leg motion of appendage

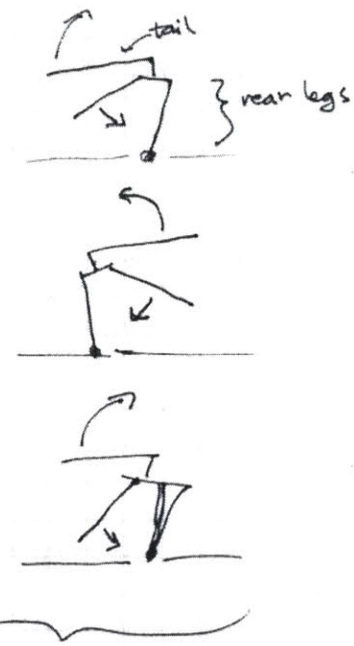
Cheetah tail.mp4

clear example 32s

back leg swinging down with tail opposing (leg closest to tail beginning position) - 1:18s

tail definitely waits until leg away from position makes placement on ground before it begins acceleration 1:20

1:21



no

these are all followed by the front legs being placed at the opposite angle in order to begin the new turn. The torso twists for this to happen.

Cheetah 2
lots of tail motion including conical rotation, but much less obvious than in cheetahtail.mp4

2-20-12

When you watch Murata girl traversing a beam that is S-shaped, it seems quite clear that she must have a reaction wheel with a vertical spin axis since she is able to twist the whole body without any outside influence.

Lot's of space at back of robot that is not being used otherwise.

Tail would require less mass since you would need at least two reaction wheels to help with the torque component.

A tail can also provide force reactions which a wheel would not be able to do.

Lord Jesus, I love you

Tail provides coupled torques to body because of reaction force

Tail seems to be used as a reaction mass in all sorts of situations

"Reconfigurable Reaction Mass"
Key to the paper, showing that tail can be used in many different ways

Include some key simulation results that demonstrate the different motions and behaviors we describe.

2-21-12 More paper notes

from Sangbae
- tail vs. flywheel
- coupled moments
- segmented design with tuneable stiffness
- versus rigid rod
- future work on cable actuation

Purpose of experiment

- cluy impulse - show decreased settling time possibly show stability vs. instability for large enough impulse
  energy shaping controller
- moving platform - shows stability vs. instability for large enough movement
  energy shaping controller
- fixed push onto F/T sensor - shows increase in effective "stiffness", that is resistance to body motion.
  energy shaping controller ? or some kind of position controller

Paper Notes 3-1-12

Animal uses of tails

speed in animals

Dinosaur - balance weight over two legs
- curve body during walking

Birds - aerodynamic surface

mammals tails evolved according to use
long, heavy for balancing

small mammals - climbing, jumping

tail becomes short with animals that spend time underground

Kangaroo - Long heavy tail to balance
very powerful tail

Ungulates - little tail use except switching flies

1 caudal vertebrae → 49
gibbons anteaters

0 to 250% of head-body length
Salpingotus

long rear feet → long tail

Paper ~~Scheduling~~ Writing 3-~~8~~7-12

Intro

Cheetah Inspiration

3 • careful observation shows tail movement coupled with hind leg movement

2 • Many videos show tail movement, but BBC clip in particular shows clear whipping of tail with each turn

1 • Researches have noticed cheetah tail movement when maneuvering since 80's - Hildebrand

4 • We were interested to ~~[illegible]~~ explore any ways that the tail could be used for dynamic stability and increased speed in turning

w/3 • Figure of ~~leg~~ swinging down with tail whip

• Tail does not seem to be used much for straight line running, but primarily for turning and disturbance rejection (i.e. when attacking to ~~[illegible]~~ move the body into a more favorable orientation)

Tail is more generally a "Reconfigurable reaction inertia" and not necessarily a tail as we're used to thinking of one (i.e. doesn't necessarily have to protrude from rear of body), but this location is convenient

Tails have not been used extensively on robots

A few examples

- MIT Uniroo
- Iida Stumpy (in the general sense)
- Full gecko
- Full lizard car

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we focus on reaction inertia aspects but there are many, many uses seen in nature ~~that~~ that could possibly have interest to roboticists

Overview of paper

In the following sections, we hope to
- explain inspiration from cheetah
- demonstrate to the reader the inherent benefits of a tail-like appendage compared to other types of orientation control devices
- Present an experimental example ~~showing the use~~ showing how the tail can correct for outside disturbances
- Present 3D dynamics formulation for the two body case and optimization results for ideal tail use in certain circumstances

Animals ~~show~~ can give us inspiration for the many ways a tail-like appendage could be used

- balancing weight over two legs as hypothesized in dinosaur locomotion, curve body also (tail yaw rotating)
- Pitch control → energy storage as seen in Kangaroos
- disturbance rejection for climbing animals in circumstances where legs cannot be used, such as cats walking along a fence top (walker)
- gravitational moment → dinosaur Yaw control
- interacting with environment to provide forces to the body → prehensile tails in monkeys
- Aerial phase maneuvering as seen in geckos and other lizards (full)
- Defence – rolling into ball like giant pangolin, attacking like porcupine
- Tail autotomy – eject tail when attacked, use as one time escape reaction mass or projectile
- Thermoregulation – Pocket gophers – use to cool

- Biologists have sometimes referred to the tail as a "fifth limb"

tail for "swimming, crawling, running, hopping, digging, climbing, gliding, or flying"

- fifth leg → macropods, pangolins
- tail as lever to swing from → cebids
- prop to stand as tripod → beavers
- Kangaroo rat can reverse direction in midair and start hopping in opposite direction by using tail.

Tiger attack – one example of opposing appendage motion with tail

Balance in the cat

Intro + bioinspiration – 1½ page
Experimental setup and results 1½ pg
Conclusion and future work ½ pg

How do animals use their tails?
what are possible uses in robotics?
why are we interested in a tail?
where did our inspiration come from?
What ~~have~~ we found through experimentation and simulation that is of interest?
What else besides a "tail" could be used?

4-23-12

Tail Thesis

we essentially want two degrees of freedom, but we also need the capability of avoiding singularities.
~~ta~~

I'll start writing down different configurations that I've been thinking of.

But first, the functional requirements

- accelerates