

Notes from Autumn Lab visit (8/7/2003-8/8/2003)

Comments/replies by Mark C. 8/10/03

Main items from trip

- David Attenborough gecko movie. This is a must see for everyone on the project. Do we have a copy? If not, Kellar will burn us a DVD.
 - We do not have a copy. A DVD would be most welcome.
- Kellar went through his PPT presentation he was going to give at the weekly PI telecon 8/8. He says this presentation is on the UofM U-M worktools site. Mark can you download this for us. It would be good for the group to see, though it should not be posted on Twiki.
- This would be “Rise gecko.zip?” I can download and put in “Docushare/Rise Private” or on Chewie, as you prefer.
 - Setae are self cleaning
 - Many other details in presentation
- Talked about how dry adhesion works. Shear is essential!!
 - Shear unfolds and aligns the spatulae on the setal tips
 - Feet have toes in a fan pattern. The toes slide together as they shear across the surface. This is believed to be part of the preloading mechanism for the setae.
 - Ankles also pivot during sliding. They rotate to point upward to keep max shear/adhesion aligned with the gravitation vector.
- Look at Robo-Toe setup and discuss improvements for next generation of Robo-Toe 3.0 device.
 - Robo-Toe is a 2-DOF stage for measuring adhesion characteristics of setal arrays. The device uses (slow) ball screw driven actuators to: (1) preload the setal array, and (2) stroke the array over the surface. 1-axis Kistler force sensors are used to measure the preload and shear. The area of contact with the setal array is measured via TIR (total internal reflection)
 - Should the next generation Robo-Toe have one or more axes of high B/W actuation?
 - Should it have a rotational axis to investigate claw “adhesion”?
 - Do you always want to do input-motion/measure-force or would you ever want to do a controlled force?
 - Possible future Robo-Toe investigations
 - Is there a roughness at which geckos transition from dry adhesion to claws (suggest only hard surfaces to eliminate the variable of carving into the surface with claws)
 - How to classify the surface
 - (hard/soft – ratio of claw stiffness and strength to climbing surface)
 - **Roughness** (RMS feature size, concave/convex, fractal dimension) **What would be representative of the materials our robot would need to climb?**
- Looked at my wood claw prototypes. They added small cantilevered plastic leaf spring with a setal array on the end of them to one of the prototypes. **Perhaps this**

could be a good demonstration for the kickoff meeting (foot ideas and collaboration with Autumn lab).

- Let's look at this. It is getting time to start thinking of a few, high-impact slides for the kickoff.
 - Kellar also liked the **fan shaped SDM parts** that George Wuensch made a while back. He said it reminded him of the overlap of setae, which he believes is part of the preloading scheme for good adhesion of the arrays. He **bonded a couple setal arrays on the tips**. Kevin may make some more of these for Kellar to play with. **This would be another good item to bring to the kickoff meeting.**
 - OK.
- Brought back setal array samples (see quarter lift demo movie).
- Which movie is this? In the .zip file?

Robo-Toe in more detail

A small flexure holds the setal array so that very small preloads can be applied to the setal arrays.

Kellar wanted to know if we could make an SDM flexure for him. We would also use the same interface on feet we would send to him to test.

What would be the point of doing this with SDM as opposed to any other method? I am concerned that SDM is being viewed as a magic solution to anyone's design problems.

The actuators in the stage have sub-micron precision and a max speed of **6mm/s (we were wondering how this compares to the rate at which the geckos foot slides as it climbs)**. **Fyi, the available shear forces increase with stroking/sliding velocity.** The stage, in its current state is controlled through a controller box that allows a specified displacement or velocity to be applied. The next generation will have a PXI (real-time Labview) interface. I thought a **servo loop speed of 1000 Hz** would be sufficient for this (**does anyone have a strong feeling about whether this will be sufficient?**)

If it's going as slow as a few cm per second and it is motion control (not force control) then even a few hundred Hz is plenty. 1KHz is overkill and may be difficult for RT Labview to achieve.

Planned improvements for the next generation Robo-Toe .

- add PXI interface (Kellar is having a consultant write the software for him)
 - automate preload
 - program in preload profile to mimic force plate measurements.

The main question we discussed about Robo-Toe is, "what should the next generation of Robo-Toe do and what improvements will be required to do this?"

- The **main topic** discussed is whether to **add a high b/w actuator**. If so, we would have to support Kellar by helping select an actuator/sensor and amplifier/controller. There is a modest budget allocated (~\$,5000) for this so it is feasible to buy a prepackaged actuator/sensor to plug into their PCI chassis.
- Also wondered if a rotational axis should be added (useful for examining claw adhesion)
- **How will effects of peeling be addressed? Does this require a rotational axis?**
- We would also need to provide specs for the system for us, as well as the guy programming the labview interface.

Possible future experiments with Robo-Toe

Responses to questions that were posed before our visit

Clawed animals

-Is there a specific claw geometry common among animals and insects that climb?

Kevin already has one of the two references that Kellar pointed us to on Adhesion (Kevin what is the name of this book?). The second reference is B. Scherge and S. Gorb, "Biological micro and nano tribology – nature's solutions"

Perhaps in the big Endnote file that Bob Full sent us...

-Is there a specific angle that these claws optimally attach at?

Not sure. See above refs. and preprint by Gorb on claw mechanics (add ref)

See also above thoughts about rotational DOF for testing.

-Do these animals employ a specific attachment strategy (approach trajectory or progression as they plant their foot)?

Not sure, see above refs. In looking at the way geckos climb, I believe that sliding on the surface that is being climbed is important. I believe that planting the heel of the foot aligns the claw for optimal engagement against the wall. I believe that cockroaches also do this, but do their feet really slide that much?

-Do insects keep their claws sharp? How much do they wear out? Do they grow back?

We'll have to do some reading on this. Perhaps Bob knows.

And if they do keep their spines or claws sharp, HOW do they do it? Is it like a tempered shovel blade in which the core is harder than the skin so that it always wears into a sharp profile?

General Questions

How do animals handle the transitions from horizontal to vertical and vice versa? Can we get some video footage? We are interested in leg use as well as body flexion.

See videos on CD.

A convex shape (e.g. a tree) seems easy to climb whereas concave surfaces (e.g. inside a tube, with diameter larger than your arms can reach) seems challenging.

What are the ranges of concave and convex curvature that animals can climb? How are the ranges related to surface qualities as mentioned in question (1)? How do animals change their gait and force exertion patterns?

We don't know. We discussed this a bit, and Kellar agrees that this would be interesting to look at, but would need a new force plate. Perhaps one could start by taking measurements in a corner with flat walls. One could also vary the angle from the nominal of 90 degrees. Yes this should be fine. Set up the force plate on one side of a gently concave angle. 90 degrees may not be optimal. 45 or less might be better.

How strong are the forces of organisms clinging on to a vertical wall?

See previous Autumn and Full Papers

Can geckos stick onto Teflon? Polyethylene?

How do the forces vary depending on direction?

For geckos, force-plate measurements show that when moving on a wall, parallel to the ground, that the two side legs highest on the wall have reaction forces similar to the front feet when climbing straight up the wall.

How do the forces vary depending on surface material? surface roughness? surface cleanliness? surface temperature? surface wettability?

Don't know. We will be looking into adhesion on rough and smooth surfaces.

Can we measure this?

From Jonathan: Is there a **temperature** constraint on the material used for synthetic setae? (i.e., is it going to melt if we embed it into an SDM part?)

For synthetic setae, this is a question better directed to Ron Fearing. I would generally think heat will be less of a problem than the issue of altering the surface/adhesion characteristics of the synthetic setae.

It is a kind of urethane, so it probably has the usual urethane temperature properties. That is, not particularly temp. resistant, but compatible with the current process.

In talking with Kellar, he thinks that if we wanted to embed actual setal arrays that there would be no issues with heat up to 50 degrees C. Above this temp, the setae may dehydrate, though Kellar believes we should be able to rehydrate the beta-carotene in the setae by putting some water on them or by simply breathing on them.

I think this would be very interesting to try! A useful early accomplishment. But I think it would be a waste of time if we don't design a proper substrate – perhaps with toes .

Otherwise, we'll get disappointing results.

Kellar believes that embedding real setae in wax (for handling purposes in SDM would make them useless because we would never get the wax out of them). Interesting... even with solvent?

What kind of shock absorption motions do animals show when landing after a fall? (Cats are very good at absorbing shock when landing.)

My guess is they don't need to. I think we need to start looking more at animals that weigh 1Kg and more. There are no 1+ Kg geckos or insects... this may tell us something about the limitations of the principles they use. Even a squirrel can fall from a tree onto the forest floor without harm (I've seen it happen).

Do insects do anything? Like a judo practitioner would know how to minimize impact. (e.g., Bring limbs close to their body to prevent breaking them, tightening up muscles, etc.)

Do they even notice that they are falling? (I guess yes, at least in some cases, because insects that can fly just start to do so)

What is magnitude of the force or acceleration an animal experiences at such a landing?

Most importantly, at what size do animals begin to show active reflex to reduce landing impact? (Assuming that insects don't do very much, and cats and squirrels do)

Kellar mentioned an experiment where a researcher dropped a mouse down a mine shaft and it survived. Then he dropped a rat down and it did not survive. Apparently animals that are mouse-sized and smaller can survive a fall from unlimited heights. (see McMahan and Bonner's "One size and life." This is out of print but should be in the library).