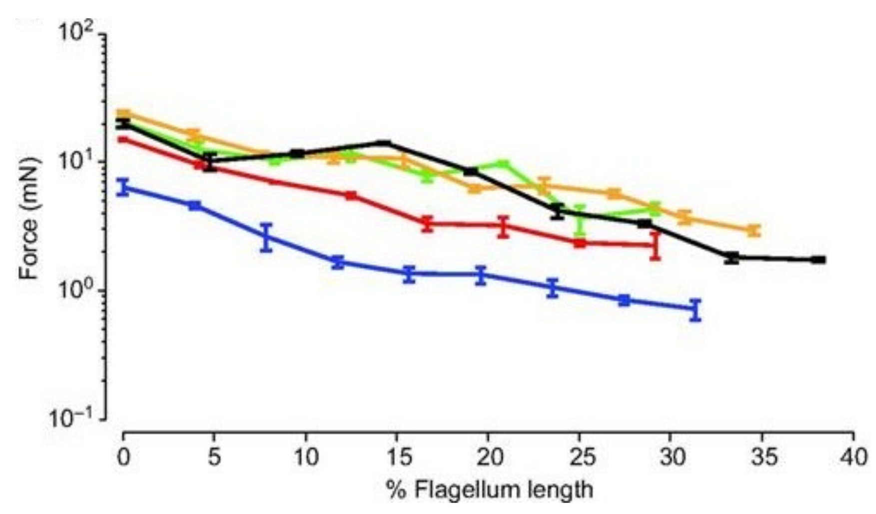
Instrumentation Design for the nN-Level Flexural Force Measurement of Cockroach Antennae

Sam van Zyverden, Mechanical Engineering – Penn State University
Advisor: Jean-Michel Mongeau

Introduction

Cockroaches use their antennae to sense and navigate during both high-speed escape and low-speed exploration. Comprised of a viscoelastic fluid surrounded by a ~150 segment rigid shell, these soft, critically-damped structures contain 40,000 mechanical sensilla that detect the antennal movement and contact features. By studying the mechanical properties of the antenna, engineers can use them as inspiration for new soft and distributed robotic sensors capable of tactile sensation and navigation in complex terrain based on touch. A fundamental property of the antenna is its flexural stiffness. Limited by the mN level resolution of a commercial force sensor, the resistance-to-bending force of the antenna has been measured only along the first 35% of its length [1].

(Microscope view of the antennas jointed flexibility)



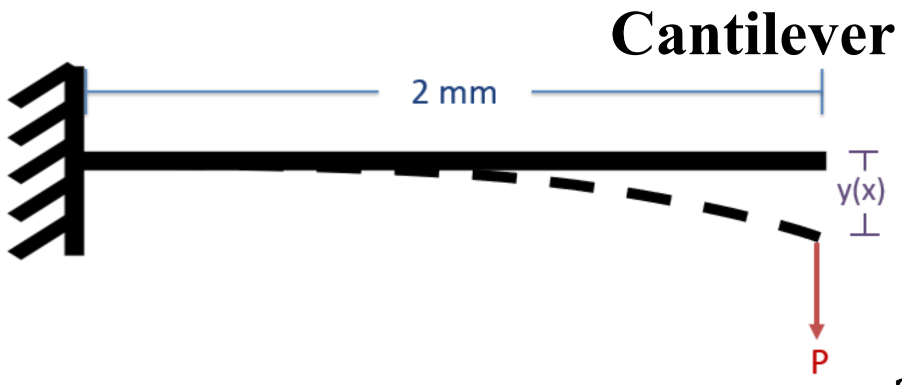
Objectives

- Design instrumentation to measure the resistance-to-bending force of a cockroach antenna with nN level resolution
- Develop method to perform the force measurement experiment while keeping the cockroach alive and healthy

Methodology

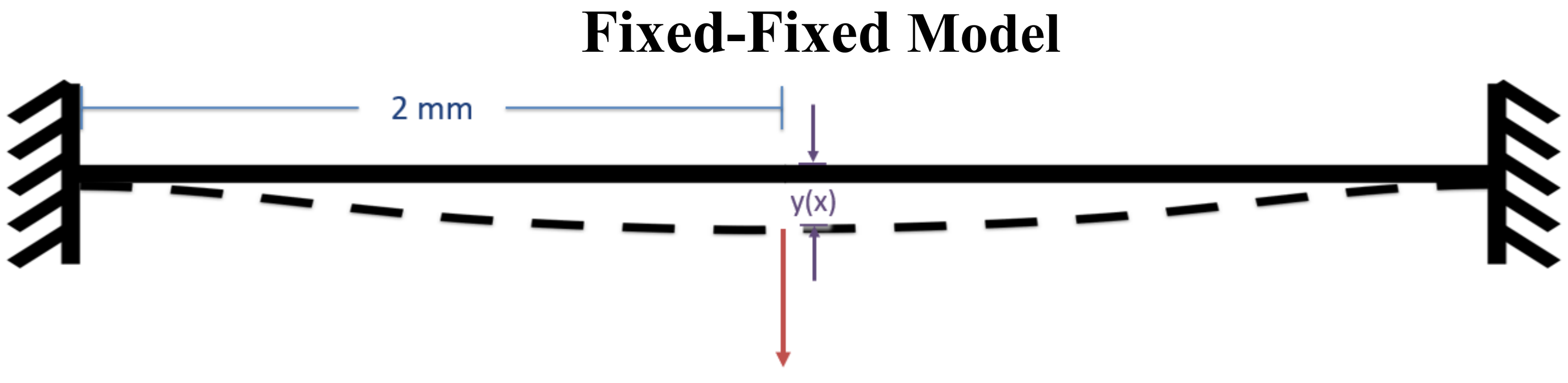
Previous resistance-to-bending force measurements have been conducted using a cantilever model of the antenna. Comparing this with a beam fixed at both ends using an Euler-Bernoulli beam model:

Cantilever Model



Reaction Force: $P(x) = \frac{3EIy}{L^3}$

Fixed-Fixed Model



Reaction Force: $P(x) = \frac{192EIy}{L^3}$

Boundary conditions significantly impact effective stiffness in a structural system, even though the intrinsic properties (E and I) remain unchanged. By fixing each section at both ends, the force resolution increases by a factor of 64.

Acknowledgements

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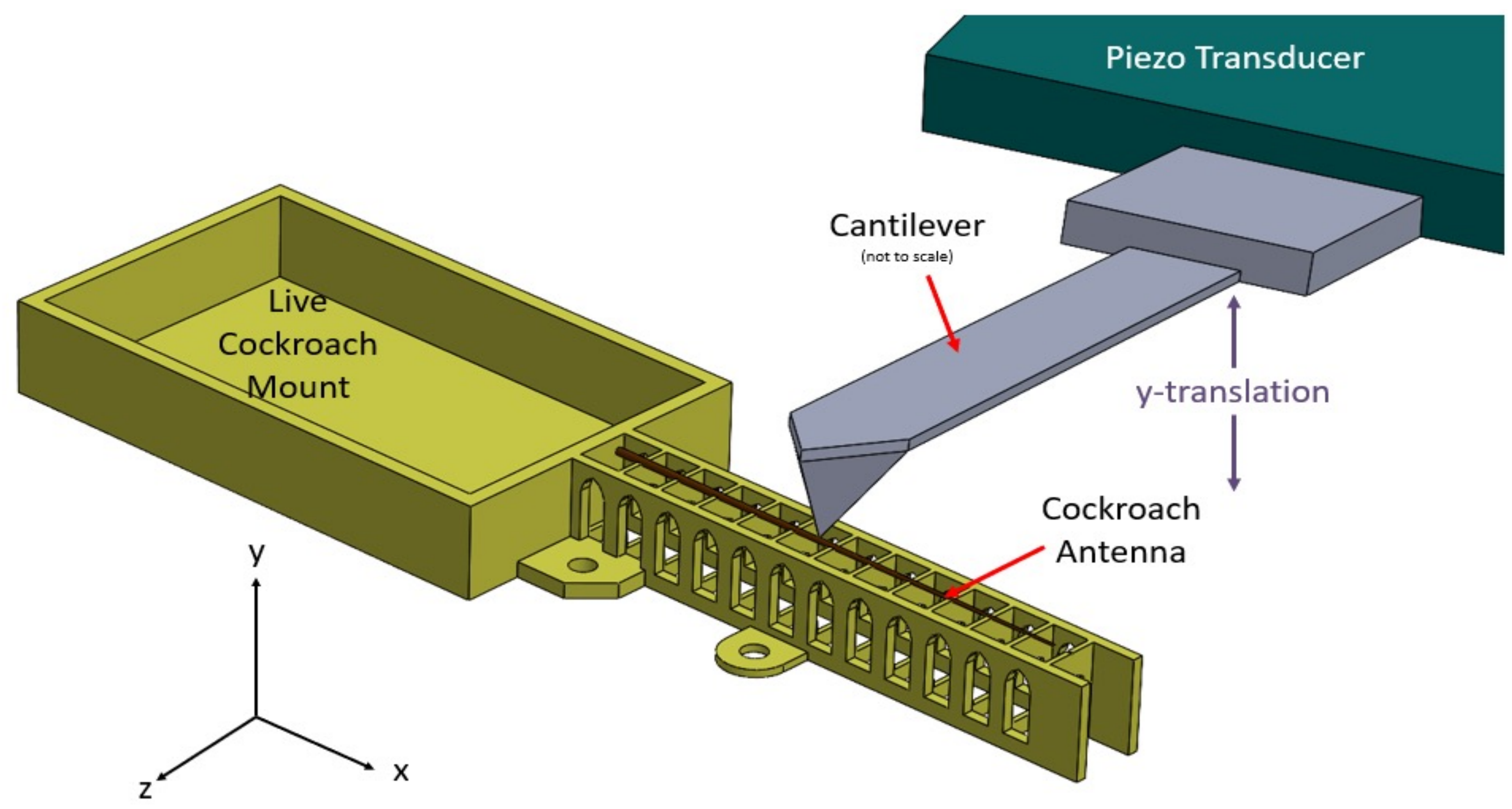
Design Results

Standard Atomic Force Microscope (AFM) Operation:

1. A microscopic cantilever probe is moved close (order of angstroms) to a surface.
2. The probe and surface experience an attractive atomic force (i.e. Van der Waals forces, electrostatic forces) that displaces the cantilever and changes the voltage in the piezo transducer at the base of the cantilever.
3. The displacement of the cantilever can be used to create a 3D topographic map of the surface.



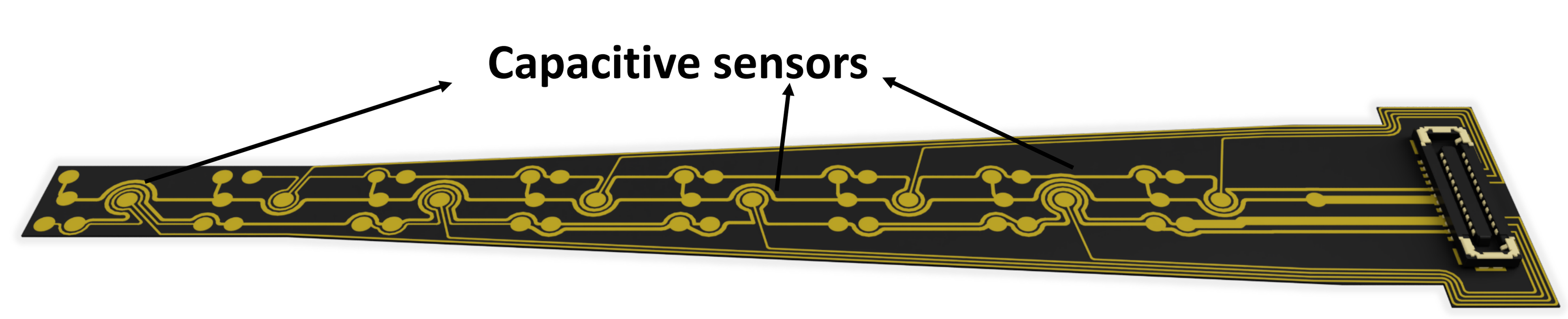
Modified AFM Procedures for Bending Force Measurement:

1. The probe will be brought into contact with the antenna in the middle of the first 4 mm fixed-fixed section of antenna.
2. The cantilever will translate downward 2 mm in the y-direction.
3. The calibrated ΔV of the transducer will measure the displacement of the antenna and cantilever.
4. Using the known spring constant of the cantilever and displacement of the antenna, the reaction force of the antenna on the cantilever can be calculated and repeated at each section. A resolution in the nN range is achievable with the proper selection of cantilever stiffness.

(A cockroach fixed to mount with antenna attached to bending support structure)

Future Objectives

- Make use the mechanical properties of the antenna of the antenna to design soft robotic antennae for tactile robotic sensation.



- Build a neuromechanical model of antennae to understand the transmission from mechanical stimuli to brain neural activities.

References

1. Mongeau J.-M., Demir A., Dallmann C. J., Kaushik J., Cowan N. J., Full R. J. (2014). Mechanical processing via passive dynamic properties of the cockroach antenna can facilitate control during rapid running. J. Exp. Biol. 217, 3333-3345.