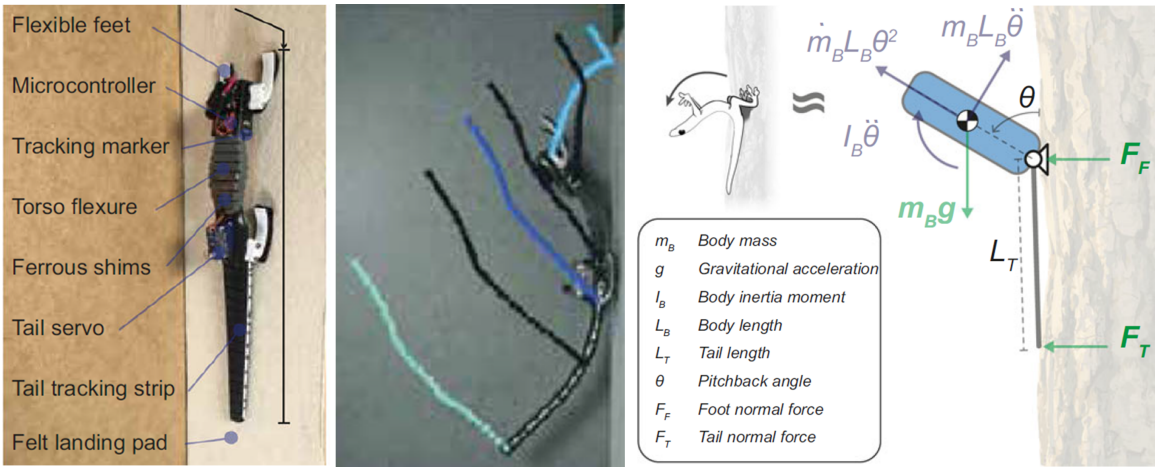
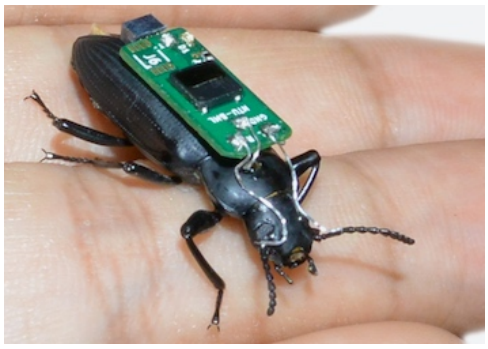
ENGN/BIOL 267: Bioengineering and Bioinspired Design
Winter 2023
Course webpage:`https://erickson.academic.wlu.edu/teaching/bioE_w2023.html`

(a) *A. aurita* and bioinspired jellyfish robot patrolling coral reef



(b) Flying gecko: robot and dynamic model



(c) small, agile insect biobot

Figure 1: Some examples of biological inspiration. Image credits: (a) [1] and Getty Images/Oleg Kovtun, (b) [2], (c) [3].

In this class, we will study form and function; distill physics and engineering principles inspiring new designs and technology. The latter half of the course is dedicated to carrying design project with teammates!

Quote worthy

Look deep into nature, and then you will understand everything better. -A. Einstein

Human ingenuity may make various inventions... but it will never devise any inventions more beautiful, nor more simple, nor more to the purpose than Nature does. - Leonardo DaVinci

Course Meeting Info

When: TR 9.45–11.15 am
Where: Newcomb 122 (regular class meeting spot, for now) We will also make use of the IQ center Computer Visualization Lab and Physical-Mechanical rapid prototyping facilities.

Instructor Info

Your host DJ and selector:	J. Erickson
Office Hours:	MTW 12.30 - 1.30pm
	and by appointment (walk-ins welcome!)
Where to find me:	Howe 221 or Howe 222
Email:	ericksonj@wlu.edu

Course Objectives

- Integrate and apply first principles of physics, engineering, and biology/physiology to explain animal amazing behavior/mechanisms.
- Understand the variety of methods and instrumentation used to perform experiments by which these amazing animal properties/behaviors are studied.
- Apply principles employed in biological systems to investigate and create novel devices and solutions to current engineering problems—and vice-versa.
- Understand the promise, challegnes and potential limitations inherent with attempting to replicate/reverse-engineer/apply biological systems principles.

Course Overview

Animals are endowed with some truly amazing capabilities. They come standard with exquisite parts and abilities that far surpass the technology we humans currently have at hand. For example, consider the following:

- Jellyfish swim and patrol the ocean without disturbing the marine environment and they don't get caught in seaweed (your typical rotary propeller can't do that)
- From conch shells to chiton, underwater underarmor are among the strongest materials on earth. How do they do that?
- Geckos and lizards glide from tree tops, crash landing at speeds of 140 body lengths per second (230 m/s for the average human), yet they stick the landing! Building bioinspired robots can help us understand how.
- Squid and octopus can don camouflage in an instant to blend into their sea scape. Haven't seen any scuba diver pull that off!
- Mantis shrimp has amazing eyes that allow it to sense 12 difference wavelengths and polarized light more densely packed and more power efficient than the most state of the art cameras thus helping us develop new and more powerful optical devices!

So, humans have much to learn from looking deeply into Nature. Bioinspired design is about distilling the essence of amazing animal behavior via first principles of physiology and physics, then integrating what we learned into human engineered systems. We will explore and investigate the physical mechanisms and engineering principles behind the astonishing mechanisms and abilities of animals with topics including: propulsion kinematics of undersea creatures and ones one land; bioinspired materials and optical devices and neural-electric control of hybrid insect robots. We'll also explore how these animals are inspiring a new generation of technology[1]. Throughout, emphasis will be placed on study of methods and instrumentation used to perform experiments, by which these amazing animal properties are investigated and understood. During the first 4-6 weeks of the course will investigate 3-4 bioinspired design case studies. These will inform your very own original research project during the latter 6-8 weeks of the term.

Topics Covered

A wide-range of model systems may be studied which can be roughly grouped as below. Many of these could be appropriately cross-listed. It would be impossible to study all of these in depth during a 12 week term. We'll examine a good cross-section of these, and ***the systems on which we focus will be driven by student interest.*** Note that citation numbers refer to articles found in the References section[2]

[1] We'll only have time to explore a subset in this class, but our study of bioinspired systems doens't have to end there, of course

[2] Do not be alarmed by the number of papers listed here. This list hast been compiled and curated since 2010. There is so much to learn and explore in this field!

- *Fluid dynamics and propulsion*: Jellyfish and squid propulsion and robots [4, 5, 6, 7, 8, 9, 10, 1, 11]; Fish, squid, manta - and, stingrays [12, 13, 14, 15, 16, 17, 18, 19, **?**]
- *Cephalopod Camouflage (octopus, squid, etc)*: [20, 21, 22, 23, 24, 25, 26, 27, 28, 29];
- *Mantis Shrimp Eyes and New Imaging Devices*: [30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42];
- *Plants*: Dandelion Seeds [43, 44, 45], Hogberries [46]; Cucumber tendrils [47]; Venus fly trap [48];
- *Bioinspired robots*: Aquatic and aerial species[49, 50, 51, 52, 53, 54, 55, 2, 56]; Insect biobots (cockroaches and flying beetles) [57, 58, 59, 60, 61, 62, 63, 64, 65, 3, 66]
- *Materials*: Impact-resistant materials (conch shell, alligator skin,etc) [67, 68, 69, 70]; Superhydrophobic diving bell spider [71, 72, 73]; Spider vibration-sensing hairs [74, 75, 76, 77]; Gecko feet [78, 79, 80, 81, 82]; Mussels threads [83]; Locust wings [84]; Beaver-inspired wetsuits [85]; Porcupine-quills [86]; Acceleration-minimizing diving kingfisher beaks [87]
- *Electricity and Magnetism*: Shark prey sensing and Electric eels discharging [88, 89, 90, 91, 92, 93, 94, 95]
- *Emergent Swarm Behavior*: Fish schooling and bird flocks [96, 97, 98, 99, 100, 101]; Ant colonies and rafts [102, 103]

Course Readings

We will read and discuss articles from a variety of sources, and journal articles will constitute our primary readings. Some will be recent publications, others will be classics in their field. Articles and other readings will provided in electronic format, linked on the course website. An accompanying summary will orient to and help you navigate this fairly dense technical literature. Come with well-informed questions and prepared to discuss!

Other sources

Two keep abreast of new developments, two excellent journals (my personal favorites) that you are encouraged to browse regularly are:

- *Biomemetics and Bioinspiration* (`http://iopscience.iop.org/1748-3190/`)
- *Journal of Experimental Biology* (`http://jeb.biologists.org/`)
- *Royal Society Interface: Biomimetics* (`https://royalsocietypublishing.org/topic/subject-codes/29?seriesKey=rsif&tagCode=`)

Assignments and Grading

Class discussion and engagement

We will study and parse out some dense technical literature in this course. We will also learn and apply new analysis methods (e.g., kinematic video analysis). Discussion and team work, therefore, are essential. Please come finally prepared each day to fully engaged. This does NOT imply you are expected to know all the answers, rather that you have grappled with the material on your own ahead of time to ask informed questions and venture well-informed answers. Be prepared to work on challenging problems, to learn, to have fun1

Problem sets

These will be assigned and collected for each of 3–4 modules we study during the first few weeks of the course. Please write homework in an orderly, legible manner. Your solutions should contain the following: a brief recapitulation of the problem; a brief (one or two sentence) explanation your analysis method; algebraic form of equations first, followed by plugging in of numbers; and the final result with a box around it.

Design/Research Project

The cornerstone and highlight of this course is the design/research project, which will last approximately 6–8 weeks. Working in interdisciplinary groups, students will design and execute an original research project, likely drawing inspiration from the material presented in the course. It is an opportunity for you and your team to invent and explore, so choose a bioengineering design problem of particular interest to you. *Topics can be wide-ranging, but must be approved by the instructor.* More details will be provided later in the term regarding the time-line and requirements of the project. A final written report and oral presentation is required for all students.

Grading

Letter grades will be assigned primarily on a numerical score basis, but will also be influenced by the instructor's subjective assessment of your overall competence and performance (more on this in a minute). The percentage of each component contributing to your grade is listed below.

In-class Participation/Engagement	15%
Problem Sets	30%
Design Project: Choose Your Own Adventure:	50%
Intellectual growth and independence	5%
Total	100%

Your final state of competence is much more important than your overall numerical average. The subjective component is simply a mechanism by which—*when appropriate*—I can translate your final state into an appropriate letter grade. Throughout the term

we will have many occasions to interact in the classroom. At the end of the 12 weeks together I gain a very good sense for placing students on the spectrum of "who really knows their stuff." Factors considered during this evaluation include, but are not limited to: class participation, intellectual growth, demonstrated overall integrity and competency in course work. Please know that this policy is in place neither to hurt nor help you. If you have any questions about this grading policy, please come talk to me.

COURSE POLICIES

Course Policies and Environment

We're all good and sensible people. Our guiding principles in class 1) Do The Right Thing and 2) follow The Golden Rule. Below is a more specific collection of guiding principles:

- Collaboration: Absolutely, positively collaborate and support one another.
- Academic honesty: At the end of the day, make sure the work you submit is yours: "Represent yourself truthfully and claim only that which is your own"
- When in doubt: just ask!
- Attendance: You are strongly encouraged to attend all class meetings. Your education, your responsibility. We have a lot of fun and learn a lot together. Please join us!
- Sick days: ***If you are sick, please stay home***, get some rest, and feel better soon! This is especially important in light of COVID-19 still circulating in our community with some unfortunate new varaints—not to mention other seasonal viruses. Be sure to have a designated 'sick-day buddy' who can share news and notes from any sessions you have to miss. We'll collectively make sure to get you caught up asap.
- Athletics, music, university sanctioned events: Kindly give the instructor a heads-up ahead of time, so I know you are gone for good reason and not just flaking out. Good luck at your game, concert, etc!
- Electronic devices—Be courteous and fully engaged: Feel free to use your laptop for doing only things directly related to course work (pulling up journal articles, project work, etc.) BioE is no texting/no playing on your phone zone. Thank you in advance for helping make the most of our short time together and making our class the best learning environment it can be.

Figure 2: BioE is a No Texting Zone.

Academic Accommodations

W&L makes reasonable academic accommodations for qualified students with disabilities. All undergraduate accommodations must be approved through the Title IX Coordinator and Director of Disability Resources, Elrod Commons 212, 458-4055. Students requesting accommodations for this course should present an official accommodation letter within the first two weeks of the term and schedule a meeting outside of class time to discuss accommodations. It is the student's responsibility to present this paperwork in a timely fashion and to follow up about accommodation arrangements. Accommodations for test-taking must be arranged with the professor at least a week before the date of the test or exam, including finals.

Inclusive and Supportive Classroom (and beyond)

Together, we strive to make our classroom a welcoming and positive space where we respect, support, and encourage one another.

To help create and maintain this learning environment, please come have an earnest chat with me if:

Something was said or done in class by anyone (instructor included) that made you feel uncomfortable. Anonymous feedback is always an option too.

Your class performance is being impacted by personal circumstances, inside or outside of class. The Office of Inclusion and Engagement (`wlu.edu/oie`) is an excellent resource too.

You have a name and/or set of pronouns that differ from those that appear in your official W&L records and you feel comfortable sharing them. (For a more complete discussion: `lgbtq.wlu.edu/pronouns`)

Suggestions and Feedback

Suggestions for improvement, constructive criticism, and positive feedback are welcome at anytime. Please do not hesitate to approach me with any concerns you may have about this course. I take your feedback very seriously and will sincerely respond to all received comments. It is the main mechanisms by which the course will improve over time (sometimes instantaneously, when possible!).

References

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